RADIATION

ATOMS All matter is composed of atoms. Each atom consists of a small dense nucleus with a radius of about 10^{-14}m, and a surrounding “cloud” of moving planetary electrons that travel in orbits with radii of about 10^{-10}m. The electrons have a small mass compared to the nucleus. Atoms differ from one another in the constitution of their nuclei and in the number and arrangement of their electrons.

The Nucleus

There are two important, fundamental particles within the nucleus: protons and neutrons. Either particles may be referred to as a nucleon. Protons carry a positive charge, equal in size but opposite in sign to that carried by the electrons, while neutrons have no charge. Protons and neutrons have nearly the same mass,

Since the atom is electrically neutral, thus the number of protons inside the nucleus must equal the number of protons outside the nucleus. The atomic number (z), which represented the number of electrons cretside the nucleus, also represents the number of protons in the nucleus.

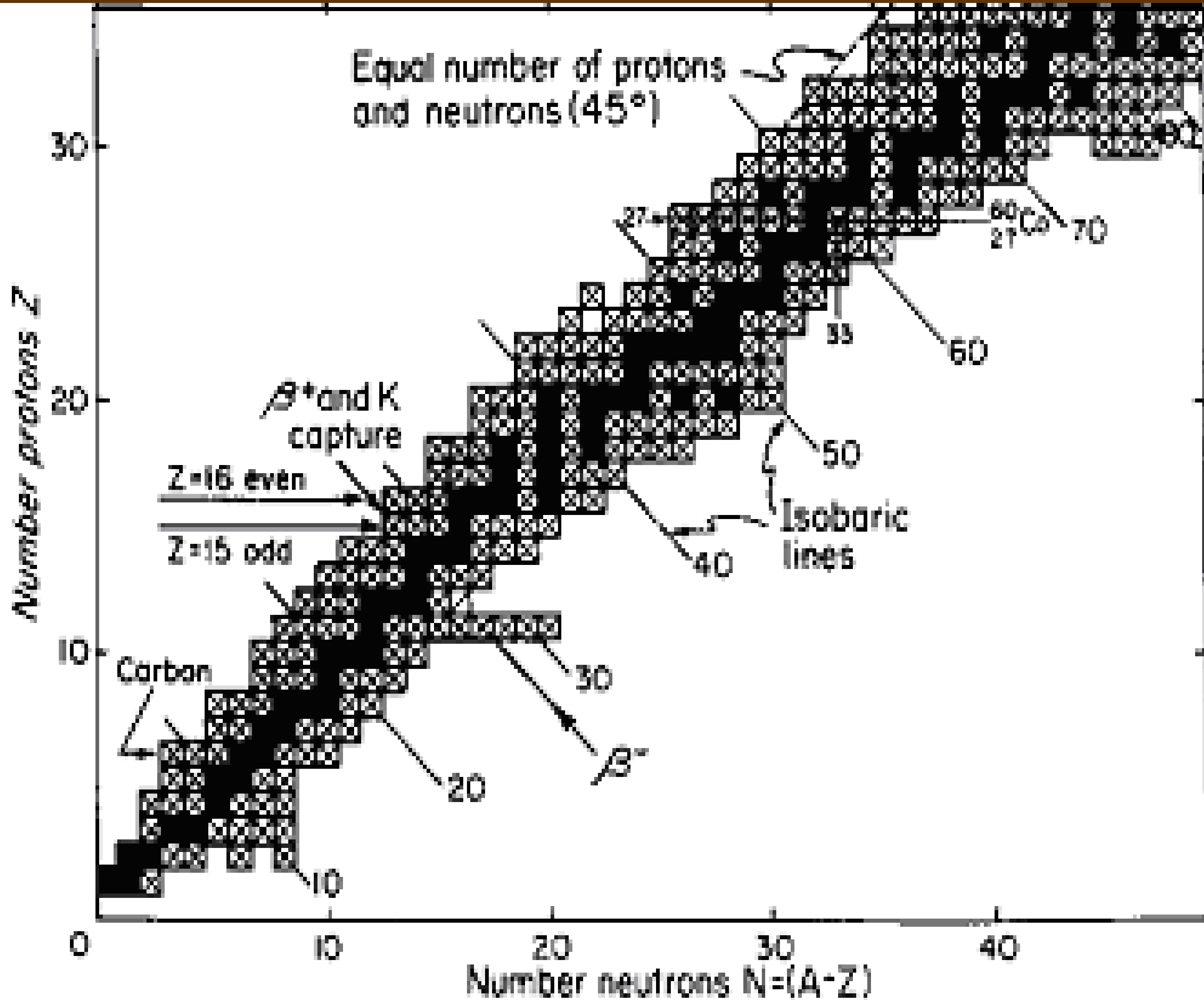
Mass number (A) represents the total number of nucleus, while the number of neutrons is given by (A-z).

Isotopes: Atoms composed of nuclei with same atomic number but different in mass number .

Isobars: Atoms composed of nuclei with same mass number but different in atomic number.

Isotones: Atoms composed of nuclei with same mass number of neutrons but different in atomic number.

Isomers: Nuclides of the same mass number and atomic number but differ in energy content.

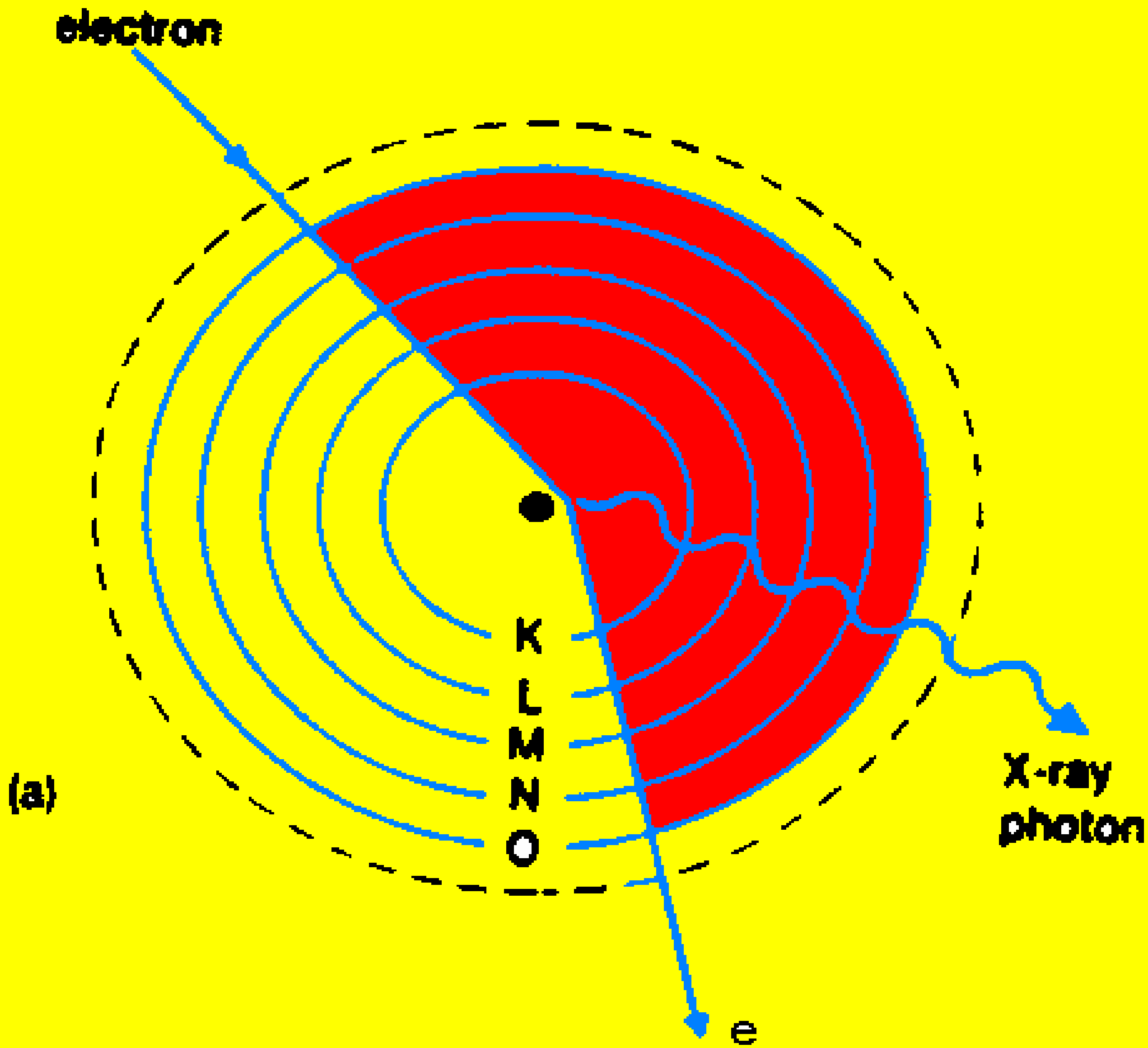


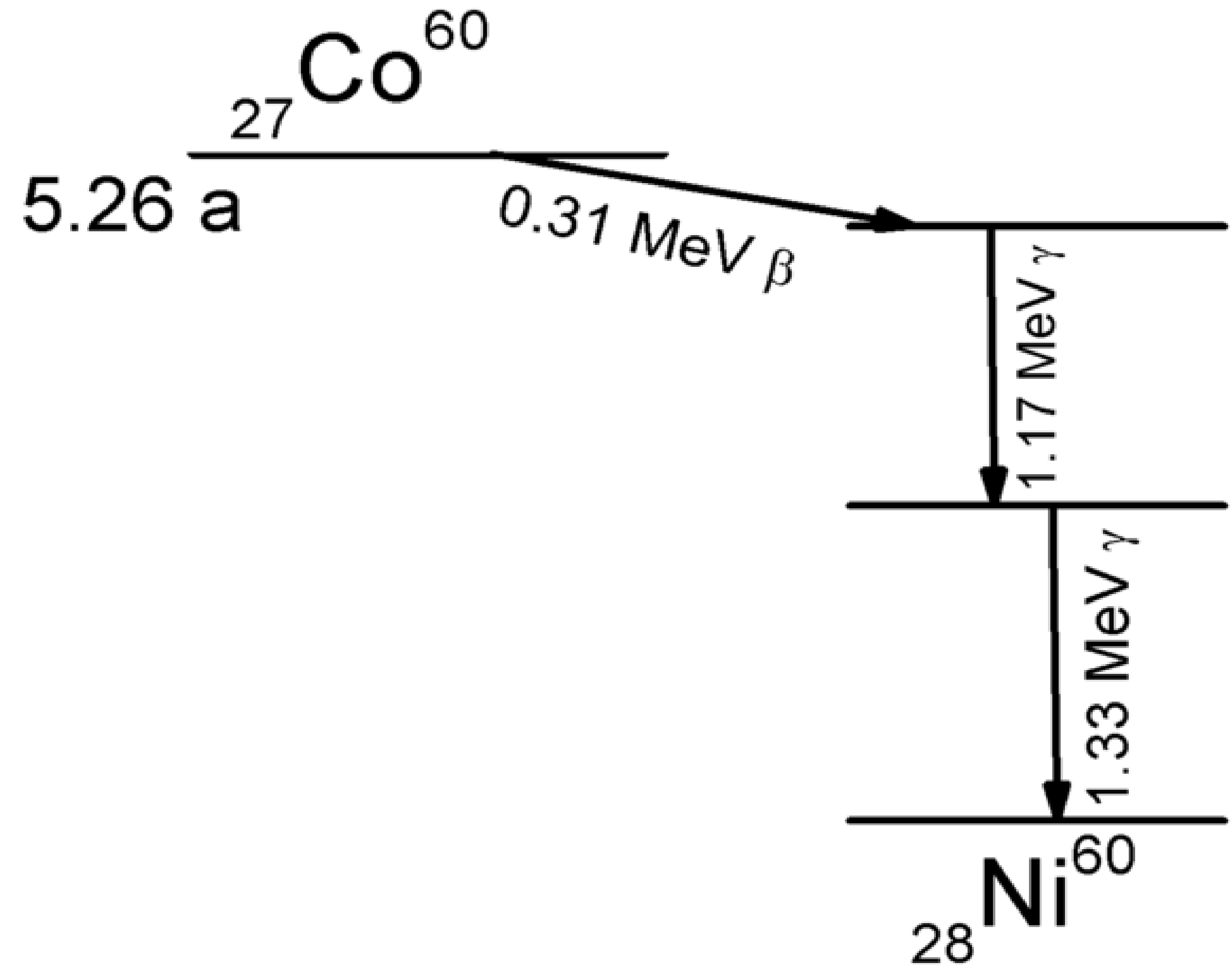
Equal number of protons and neutrons (45°)
Number protons Z
Number neutrons N=(A-Z)
β⁺ and K capture
Z=16 even
Z=15 odd
Carbon
Isobaric lines
β⁻
60 27 Co
10
20
30
40
50
60
70
0

Electromagnetic Radiation

Radio waves, heat waves, light waves, ultraviolet rays, x-rays and gamma rays are all examples of electromagnetic radiation. They all travel in vacuum with a velocity of

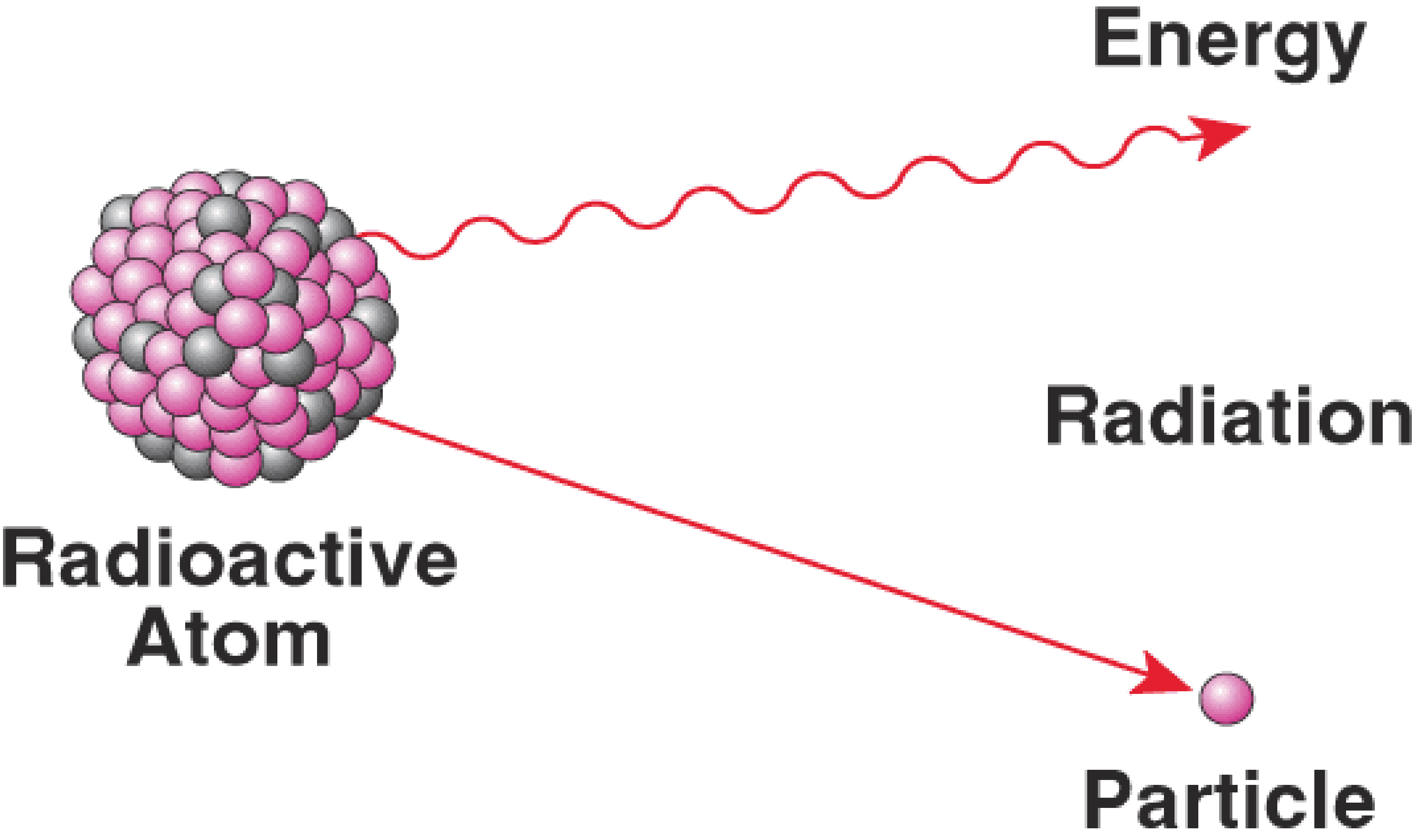
$C = 2.998 * 10^8$ ms-1 $= 3 * 10^8\ ms^{-1}$

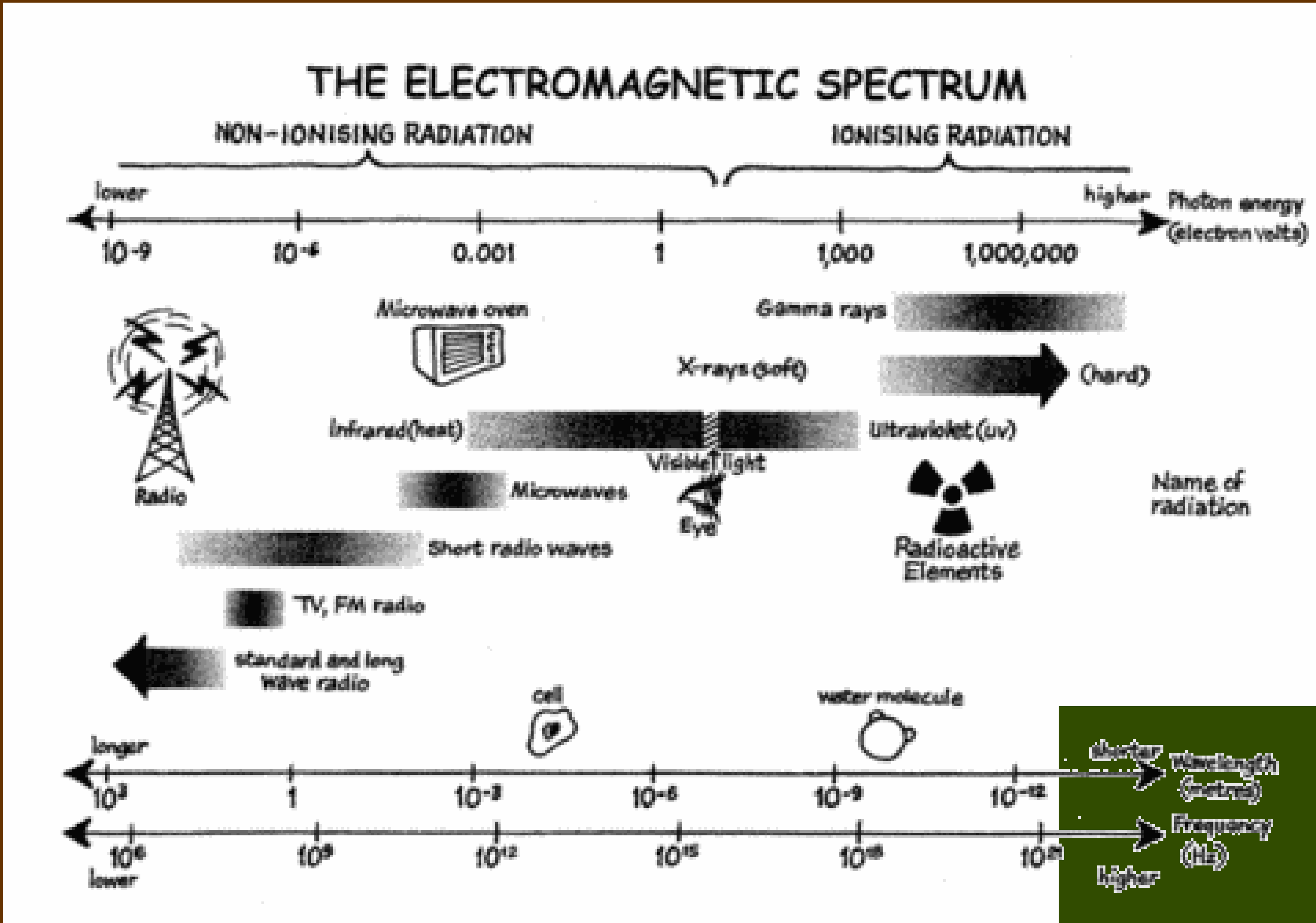

electron
K
L
M
N
O
(a)
X-ray
photon
e



27Co60
5.26 a
0.31 MeV β
1.17 MeV γ
1.33 MeV γ
28Ni60

1-Radio-isotopes as a source of gamma rays




THE ELECTROMAGNETIC SPECTRUM
NON-IONISING RADIATION
IONISING RADIATION
lower
higher
Photon energy (electron volts)
10-9
10-6
0.001
1
1,000
1,000,000
Microwave oven
Gamma rays
X-rays (soft)
(hard)
Infrared (heat)
Ultraviolet (uv)
Visible light
Radio
Microwaves
Eye
Name of radiation
Short radio waves
Radioactive Elements
TV, FM radio
standard and long wave radio
cell
water molecule
longer
shorter
Wavelength (metres)
Frequency (Hz)
higher
lower

If a source of light makes f vibrations per second and the length of each wave given off is λ, then in one second the wave disturbance will travel from the source and the velocity of the wave is. For electromagnetic waves we have the important relation:

$$\lambda f = C \qquad (1.1)$$

Quantum Nature of Radiation

Although often electromagnetic radiation appears to have the properties of waves, at other times it behaves more like a stream of small bullets, each traveling with velocity, C and each carrying a certain amount of energy. This bundle of energy is called a quantum or photons. The amount of energy carried by the photon depends upon the frequency of the radiation.

The actual amount of energy carried by a photon is given by the important relation

$$\boldsymbol{E = hf = hc/\lambda} \qquad (1.2)$$

Where h is Plank's constant

$= 6.63 \times 10^{-34}$ JS.

Problem:

Calculate the energy carried by one photon of radiation produced in a diagnostic x rays generator at a wavelength of 10Pm (Ans. 124KeV).

If we substitute in equation (2) for h and C one will get the important relation

$$E = \frac{1240\ KeV\ Pm}{\lambda} \qquad (1.3)$$

Where λ is measured in Pm.

Mass and Energy

One of the most important concepts of Einstein’s theory of relativity is that mass is a form of energy and the two are related:

$$E = mc^2 \qquad (1.4)$$

Where C is the velocity of light. Since the velocity of light squared is an enormous number, a small mass, m, will yield an huge amount of energy, E.

Ex. Calculate the energy release in the inherent of an electron

($m = 9.9109 \times 10^{-31}$ Kg)

$$E = mc^2$$

$= 9.109 \times 10^{-31} Kg (2.998 \times 10^{8})^2 \ m^2 \ s^{-2}$

$= 81.87 \times 10^{-15} \ J \times (1/1.6 \times 10^{-19}) \ eV$

$= 0.511 MeV$

1 electron mass = 0.511MeV

As mentioned before $^{16}\boldsymbol{O}$ is considered to be the standard physical atomic weight scale and taken to be exactly 16,000,000 mass units.

1 amu = 1.66×10^{-27} Kg

Energy equivalent of 1amu is given by:

$E = mc^2 = 1.66 \times 10^{-27} \times (3 \times 10^8)^2$ J

i.e. 1 amu = 931.15

The binding Energy

By Knowing the exact nuclear masses one can calculate the energy with which nuclei are self bound. If one calculate the collective masses W of the nucleus (mass of protons + mass of neutrons) and knowing the exact mass M, then the mass decrement is given by: $\Delta = W - M$ (1.5)

$$\text{Where } W = N.\, m_n + Z\, .\, m_p$$

This term represents the mass loss during the formation of the nucleus. Usually the given M includes the mass of Z electrons, in this case the mass decrement will be:

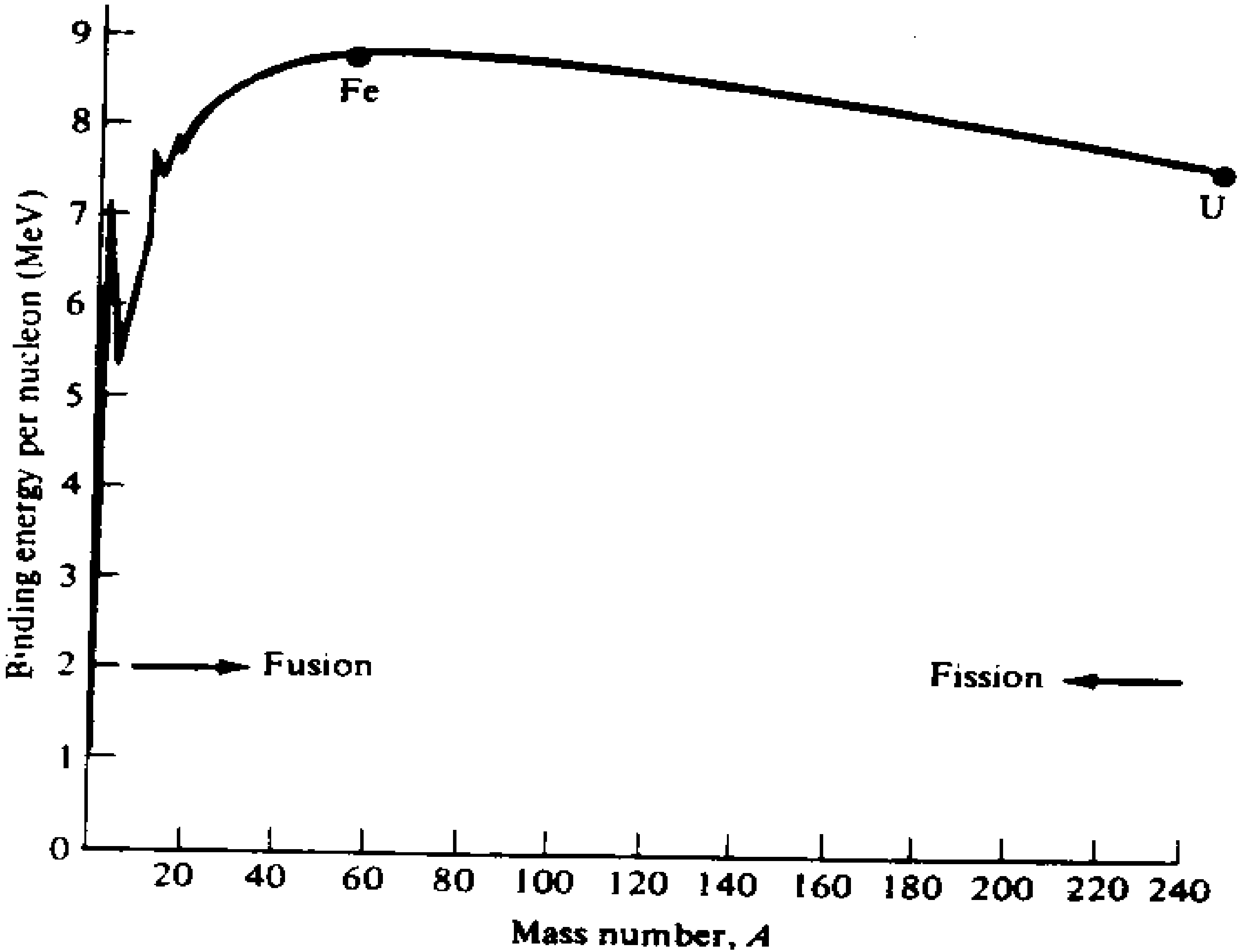
$$\Delta = (Z.\ mH + N\ .\ mn) - M \qquad (1.6)$$

The total binding energy of the nucleus is defined as the energy equivalent to the mass decrement.

B.E. = Δ x C^2 = Δ (amu) x931.1MeV (1.7)

Finally we have the binding energy per nucleon, ε:

ε = B.E. / A MeV (1.8)



9
8
7
6
5
4
3
2
1
0
Fe
U
Fusion
Fission
20
40
60
80
100
120
140
160
180
200
220
240
Binding energy per nucleon (MeV)
Mass number, A

RADIOACTVITY

Becquerel (1852 – 1908) accidentally made the first observation of purely nuclear phenomenon in 1896, 15 years before Rutherford inferred the existence of the nucleus. Becquerel noted that uranium compounds produce invisible rays or radiation that can be penetrate an opaque container and expose a photographic emulsion. Soon thereafter,

Pierre and Mary Curie showed that uranium ores are also contain traces of polonium

(Z = 84) and radium (Z = 88), both more intensely radioactive than uranium. A lead plate an inch or so thick stops most of the radiation from a uranium source , so a plate with a small hole can be used to form a narrow collimated beam of radiation .

Natural Radioactivity

The nuclear particles(protons and neutrons) within the nucleus are in continual motion. As a result of this motion, collision occurs and energy is transferred back and forth from one particle to another. Were it not for the strong forces of attraction that exist between the nuclear particles, such particles would escape from the nucleus and new nuclear species would be formed.

In a stable nucleus, no particle ever acquires enough energy to escape; however, in a radioactive nucleus, it is possible for a particle, by a series of chance encounters, to gain enough energy to escape from the nucleus. The ejection of a nuclear particle is pure chance, and there is no way to decide when any particular nucleus will disintegrate.

However, if there are many nuclei, a certain percentage will disintegrate in a given time. In the disintegration process, alpha particles, beta particles, or gamma rays may eject.

In most of the lighter atoms, with z < 82, there is at least one configuration of nucleons that is stable. Evidently, in these, the forces of attraction between particles are sufficient to prevent their random escape. All elements with z greater than 82 (lead) are, however, radioactive and disintegrate through long series until stable isotopes of lead are formed.

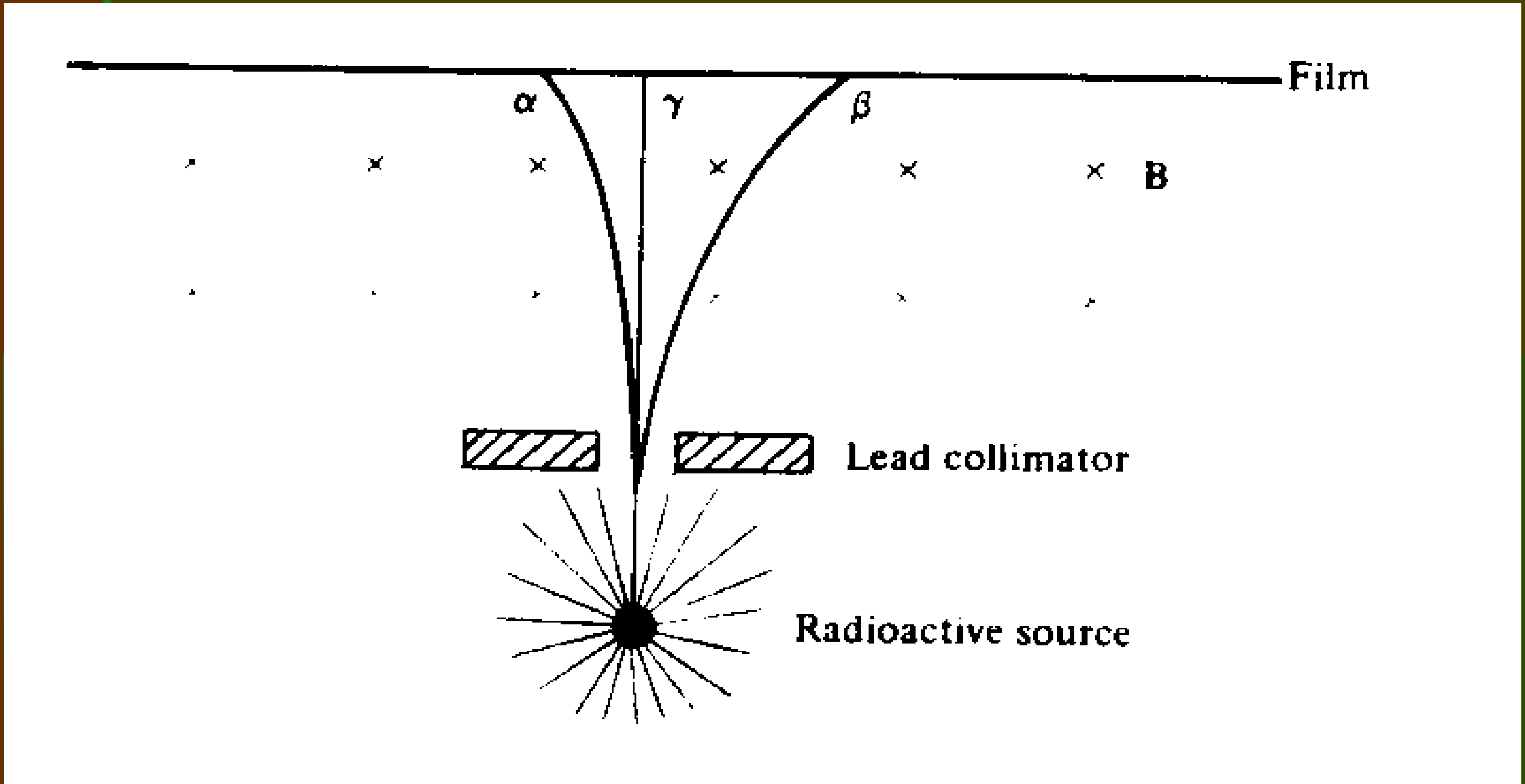
Artificial Radioactivity

With the development of high energy accelerators , and the nuclear reactor-many new radioactive isotopes have been discovered. New isotopes are produced by bombarding stable nuclei with neutrons, high energy protons, deuterons, alpha particles, or gamma rays.

A few of these projectiles will make a direct collision with the nucleus and will be absorbed or will eject some particle from the nucleus to form a new substance. The probability of such a collision is very small because the cross-sectional area of the nucleus is only about $10^{-25} cm^2$.

It follows that to produce any appreciable amount of radioactive material from stable nuclei, that is an amount that could be separated chemically, the nuclei must be bombarded for long periods of time in an intense beam. When materials are exposed to intense beams for long periods of time, as in a nuclear reactor, it is possible to produce enough new material to make a chemical separation feasible.

In the presence of a magnetic field, this beam of radiation splits into three components, labeled as **alpha (α), beta (β) and gamma (γ) figure (2-1).**



Alpha particles are positively charged and have a very short range in matter, they are known to be helium nuclei ($^{4}_{2}He$).

The negatively charged beta particles have a longer range in matter and are electrons.

The neutral gamma rays penetrate further in matter. They are photons whose energies are usually greater than those of X – rays.

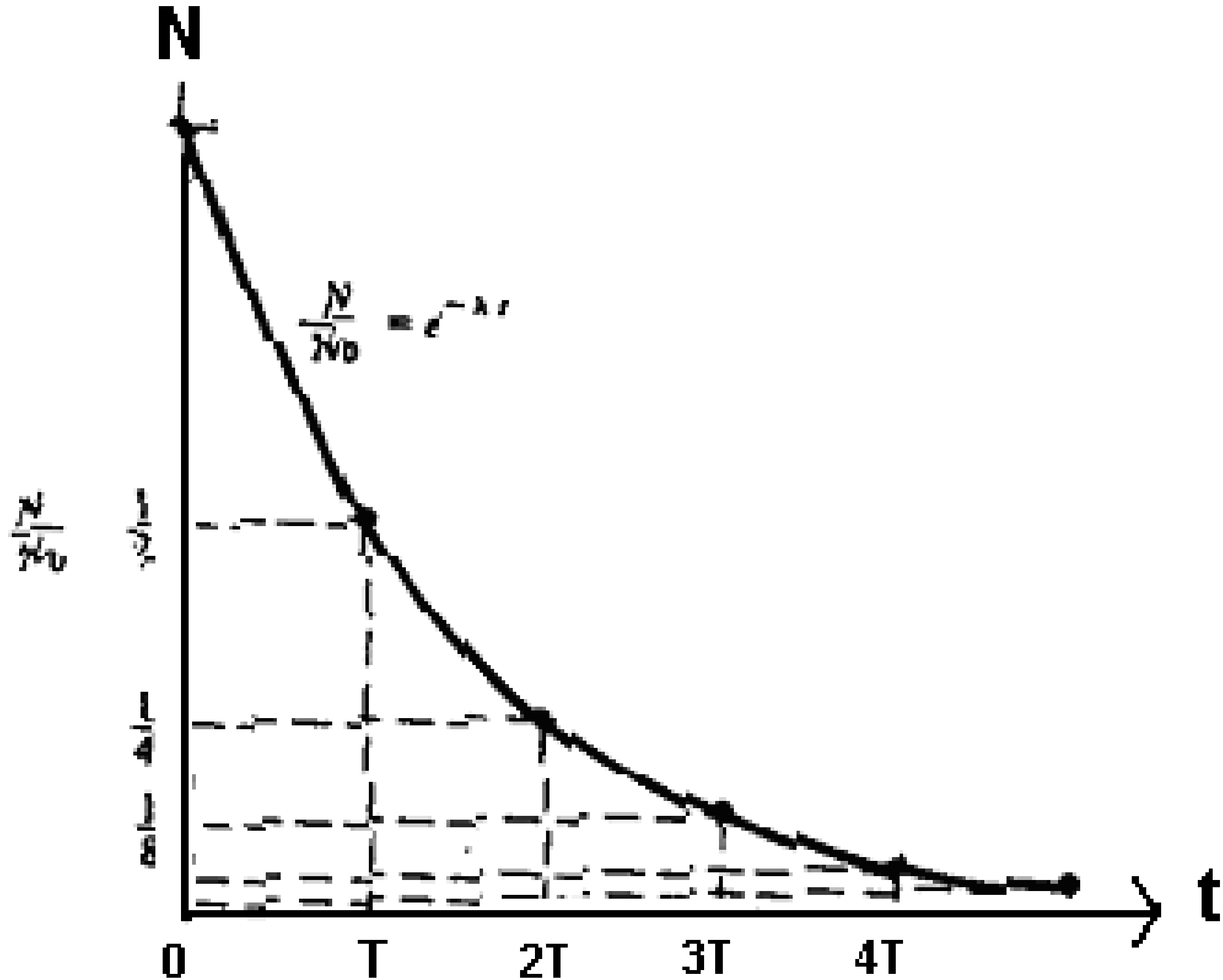
HALF-LIFE

$$\Delta N = - \lambda N \Delta t$$

$$N = N_0 \, e^{-\lambda t}$$

This equation is the exponential decay formula. At $t = T$ **(half–life)** , $N = N_0 /2$ will show that the decay constant is related to the half-life by $\lambda = \ln 2 / T$

$$= 0.693/T$$



N
$\frac{N}{N_0} = e^{-\lambda t}$
$\frac{N}{N_0}$
$\frac{1}{2}$
$\frac{1}{4}$
$\frac{1}{8}$
t
0
T
2T
3T
4T

EXAMPLE:

I- 131 is used in the treatment of thyroid disorders its half-life is 8.1days. If a patient ingests a small quantity of I- 131 and none is excreted from the body, what fraction N / N_0 remains after 8.1d, 16.2d and 60d?

If t = 8.1d i.e. t = T then the fraction remaining at this time is 1/2. Similarly for

t =16.2d i.e. t = 2T so $N / N_0 = 1 / 4$.

For 60days decay time: First find the value of

$\lambda = 0.693 / 8.1 = 0.0856\ d^{-1}$, then use equation (2.2)to find $N/N_0 = e^{-\lambda t}$

$= e^{-(0.0856)(60)} = 0.0059$

Thus 0.59% of the radioactive iodine remains after 60 days.

It is assumed in the previous example that no I-131 is lost from the body by biological processes is not quite correct.

Any stable element is excreted steadily from the body with a half-life is known as **biological half-life (T_B).** It is defined the time required to reduce the concentration of a particular stable element inside the body into half its original concentration.

^{59}Fe

The effective half-life time ***(T_{eff})*** is obtained by combining **the biological half-life** and the **radioactive or physical half-life** ***(T_p)*** according to the formula

$$T_{eff} = (T_B \cdot T_P)/(T_p + T_B)$$

EXAMPLE: ^{59}Fe **is injected to a patient to diagnose blood anomalies . Find its effective half-life.*(T_B=65d,T_P=46.3d)***

$$T_{eff} = (T_B \cdot T_P)/(T_p + T_B) = 0.037$$

Carbon-14 Dating

Radiocarbon dating has many applications specially in archaeology. It depends on the measuring of the activity of carbon-14 in the sample by using a detector of high efficiency (4*π* scintillation detector) .The results provides a reliable way of dating events occurring within the past 70,000 years.

The production ofCarbon-14 (half-life of 5730 years), in the environment is due to the activation of neutrons from cosmic rays to the nitrogen in atmosphere .

$$n + {}^{14}_{7}N \rightarrow {}^{14}_{6}C + p$$

Carbon in the environment is considered as isotopic carrier to carbon-14 and is ingested by all living organisms.

As the living organism dies, the input of radiocarbon stops, the ratio of radiocarbon to ordinary carbon decreases steadily as the ^{14}C decays. Thus the quantity of ^{14}C remaining indicates the date of death.

Example: A wooden plate has one fifth the **^{14}C activity observed in wooden objects. Estimate its age.(Assume ^{14}C levels in the atomsphere have remained the same.)**

$$N = N_o e^{-\lambda t} \Rightarrow \tfrac{1}{4} = e^{-\lambda t} \Rightarrow \ell n(0.25) = -\lambda t$$

$$\lambda = \frac{0.693}{5730} = 1.2x10^{-4}\, y^{-1} \Rightarrow t = 11552\, y$$

Problem: Carbon from living organisms contains ^{14}C at about the level of 1 part in 10^{12}. What is the corresponding number for a sample 40000 y old?

Problems:

1- After 36 hours the radioactivity of a nuclide is (1/16) its original value. What is its half-life?

2- How many half-lives are required for the activity of a radionuclide to decrease by a factor 64 ?

3- In diagnostic study a patient is injected with

5 μg of ^{35}S . Find T_{eff} .What percentage of this radionuclide remains in the body after 35.1d?

(T_B =22d , T_P = 87.1d)

Time(d)	0	1	2	3	4	5	6	7	8
Count rate (cpm)	455	402	356	315	278	246	218	193	171

Geuss the T_P of the radioactive material whose count rate is given above table?

Draw a graph on a semilog paper to find the T_P .

AVERAGE LIFE TIME

The activity of a radioactive isotope is given by:

$$\frac{dN}{dt} = |\lambda N| = \lambda N_o e^{-\lambda t}$$

Since the decay has a statistical nature, any single atom may have a life time from 0 to ∞ . So the average life time is :

$$\tau = \frac{\int_0^\infty t dN}{N_o} = \int_0^\infty \lambda t e^{-\lambda t} dt = \frac{1}{\lambda}\int_0^\infty (\lambda t)(e^{-\lambda t}) d\lambda t = \frac{1}{\lambda}$$

SUCCESSIVE RADIACTIVE TRANSFORMATION

^{90}Kr is one of the widely known fission products.This radioisotope transforms as follows:

$$ {}^{90}_{36}Kr \xrightarrow{\beta} {}^{90}_{37}Rb \xrightarrow{\beta} {}^{90}_{38}Sr \xrightarrow{\beta} {}^{90}_{39}Y \xrightarrow{\beta} {}^{90}_{40}Zr $$

33S ***2.72m*** ***19.9y*** ***64.2h***

The buildup of ^{90}Sr is therefore very rapid. The transformation of ^{90}Sr to ^{90}Y is very slow. On other hand the decay of ^{90}Y (T=64.2h) is very much rapid than Sr

However , a point is soon reached at which the instantaneous amount of Sr that transforms is equal to that of Y. ^{90}Y is said to be in a secular equilibrium. The quantitative relationship between isotopes in secular equilibrium may be derived

$$A \xrightarrow{\lambda_A} B \xrightarrow{\lambda_B} C$$

$$T_A \rangle\rangle T_B \, or \, \lambda_A \rangle\rangle \lambda_B$$

Notice that isotope C is stable. As $T_A \gg T_B$, the rate of formation of B may be considered constant and equal to K . According to this condition

$$\frac{dN_B}{dt} = K - \lambda_B N_B$$

rate of change = rate of formation B - rate of transformation

$$\int_{N_{B0}}^{N_B} \frac{dN_B}{K-\lambda_B N_B} = \int_0^t dt \Rightarrow\Rightarrow \int_{N_{B0}}^{N_B} \frac{d(K-\lambda_B N_B)}{K-\lambda_B N_B} = \int_0^t dt$$

solving

$$N_B = \frac{K}{\lambda_B}(1-e^{-\lambda_B t}) + N_{B_o} e^{-\lambda_B t}$$

If we start with pure *A* ,i.e. $N_{Bo}=0$, then

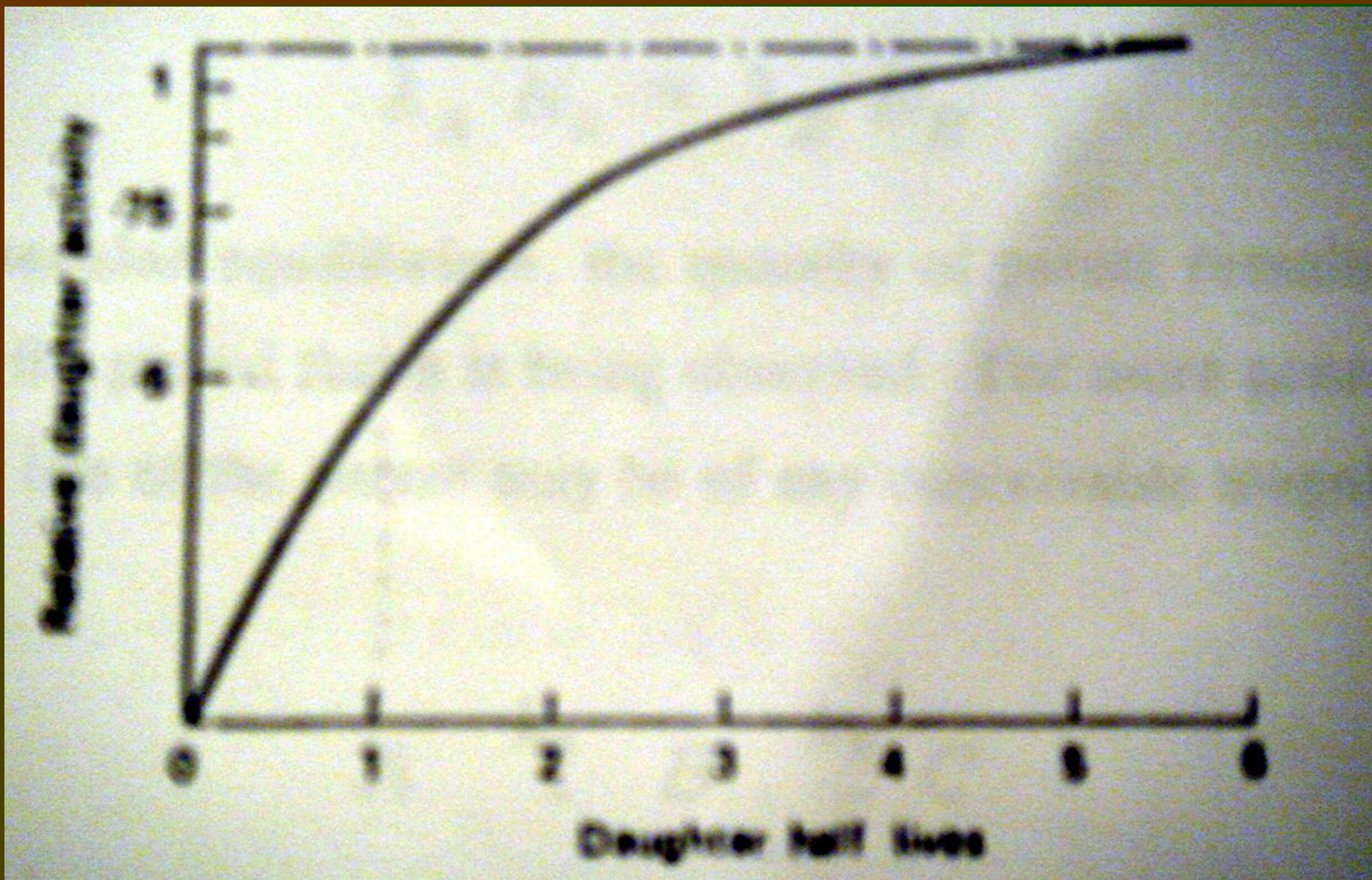
$$N_B = \frac{K}{\lambda_B}(1-e^{-\lambda_B t})$$

Notice that the rate of formation of *B* = rate of decay of *A*

$$K = \lambda_A N_A \Rightarrow then \Rightarrow N_B = \frac{\lambda_A N_A}{\lambda_B}(1-e^{-\lambda_B t})$$

In terms of activities: $A_B = A_A(1 - e^{-\lambda_B t})$

Secular equilibrium is shown in fig.



The following example will clear the secular equilibrium: If we have 500 mg radium , how much Ra-222 will be collected after 1d, 3.8d , 10d and after 100d? (T_{Rn}=3.8d and λ_{Rn}= 0.1825d^{-1}

A_{Ra}=500mg radium = 0.5 Ci = 1.85x10^{10}Bq

Using the equation;

$$A_B = A_A(1 - e^{-\lambda_B t})$$

t=1d A_{Rn}=(1.85x10^{10})(1-$e^{-0.1825x1}$)=3.1x10^9Bq

t=3.8d A_{Rn}=(1.85x10^{10})(1-$e^{-0.1825x3.8}$)=9.25x10^9Bq

t=10d A_{Rn}=(1.85x10^{10})(1- $e^{-0.1825x10}$)=1.55x10^9Bq

t=100d A_{Rn}=1.85x10^{10}Bq=0.5Ci=500mgradium=A_{Ra}

After enough long time ($7\ T_B$) the equilibrium will be established i.e. $\lambda_A N_A = \lambda_B N_B$

In the case of secular equilibrium , the quantity of parent remains substantially constant during the period that is being observed. For more general situation in which the half life of the parent may be of any conceivable magnitude . For the general case

$$A \xrightarrow{\lambda_A} B \xrightarrow{\lambda_B} C$$

The rate of change of B is:

$$\frac{dN_B}{dt} = \lambda_A N_A - \lambda_B N_B$$

Where

$$N_A = N_{oA} e^{-\lambda_A t}$$

Substitute for N_A;

$$\frac{dN_B}{dt} + \lambda_B N_B = N_{oA} \lambda_A e^{-\lambda_A t}$$

Multiply both sides by;

$$e^{\lambda_B t}$$

$$e^{\lambda_B t}\left(\frac{dN_B}{dt} + \lambda_B N_B\right) = N_{oA} \lambda_A e^{(\lambda_B - \lambda_A)t}$$

or

$$\frac{d}{dt}\left(N_B e^{\lambda_B t}\right) = N_{oA} \lambda_A e^{(\lambda_B - \lambda_A)t}$$

Integrate both sides;

$$\int d(N_B e^{\lambda_B t}) = \frac{\lambda_A N_{oA}}{\lambda_B - \lambda_A} \int e^{(\lambda_B - \lambda_A)t} d(\lambda_B - \lambda_A)t + C$$

The solution gives N_B

$$N_B = \frac{\lambda_A N_{oA}}{\lambda_B - \lambda_A}(e^{-\lambda_A t} - e^{-\lambda_B t})$$

Consider the following cases:

1- If $\lambda_A << \lambda_B$ it gives $\lambda_A N_A = \lambda_B N_B$

the condition of secular equilibrium.

If the parent half life is slightly greater than that of daughter $\lambda_A < \lambda_B$

$$\lambda_B N_B = \frac{\lambda_B \lambda_A N_{oA}}{\lambda_B - \lambda_A}\left(e^{-\lambda_A t} - e^{-\lambda_B t}\right)$$

After *a* sufficiently long decay time $e^{-\lambda_B t}$ will much smaller than $e^{-\lambda_A t}$ consequently;

$$\lambda_B N_B = \frac{\lambda_B \lambda_A N_{oA}}{\lambda_B - \lambda_A} e^{-\lambda_A t}$$

$$\lambda_B N_B = \frac{\lambda_B \lambda_A}{\lambda_B - \lambda_A} N_A$$

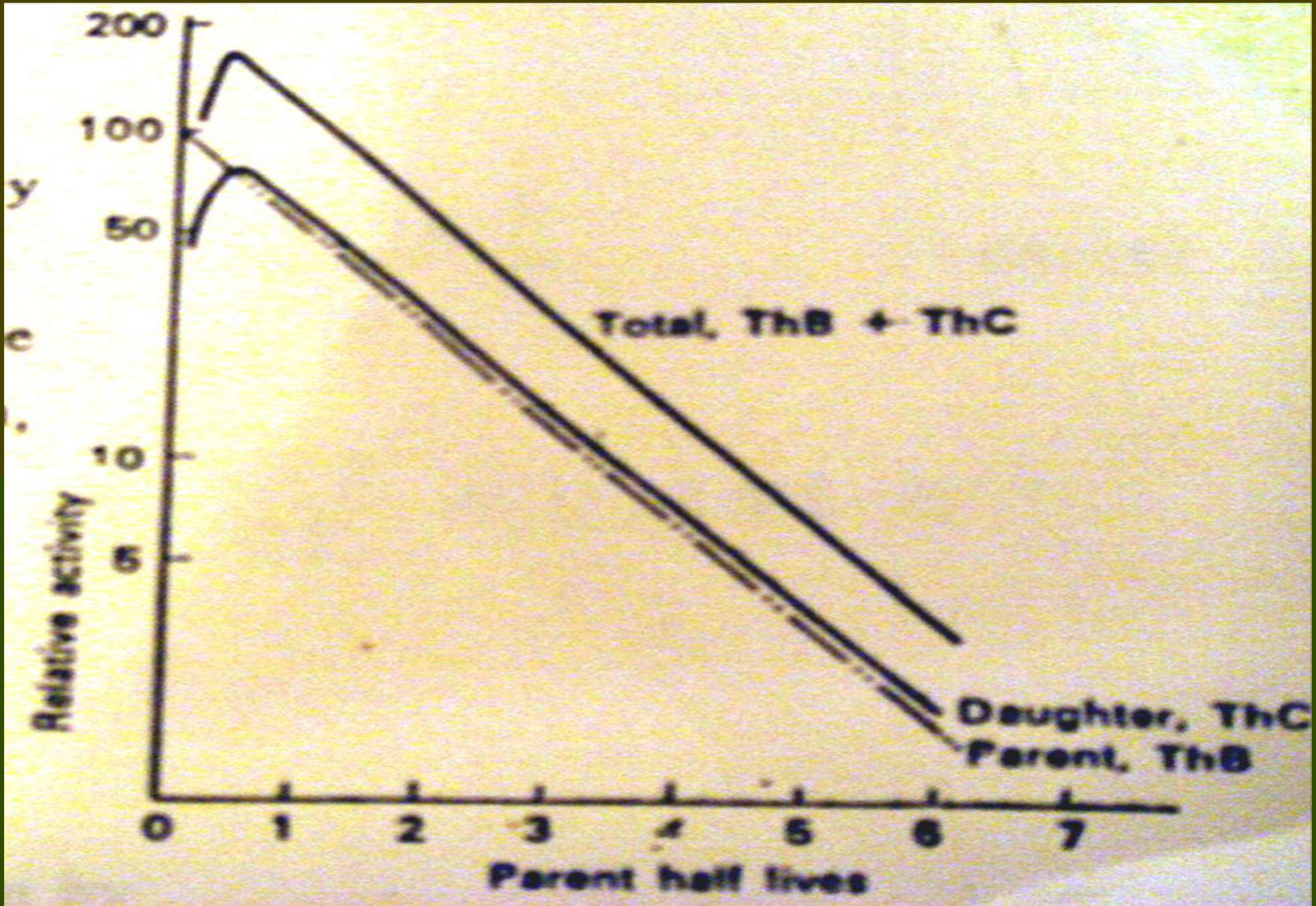
Transient equilibrium

$$A_B = \frac{\lambda_B}{\lambda_B - \lambda_A} A_A$$

A good example for the transient equilibrium is;

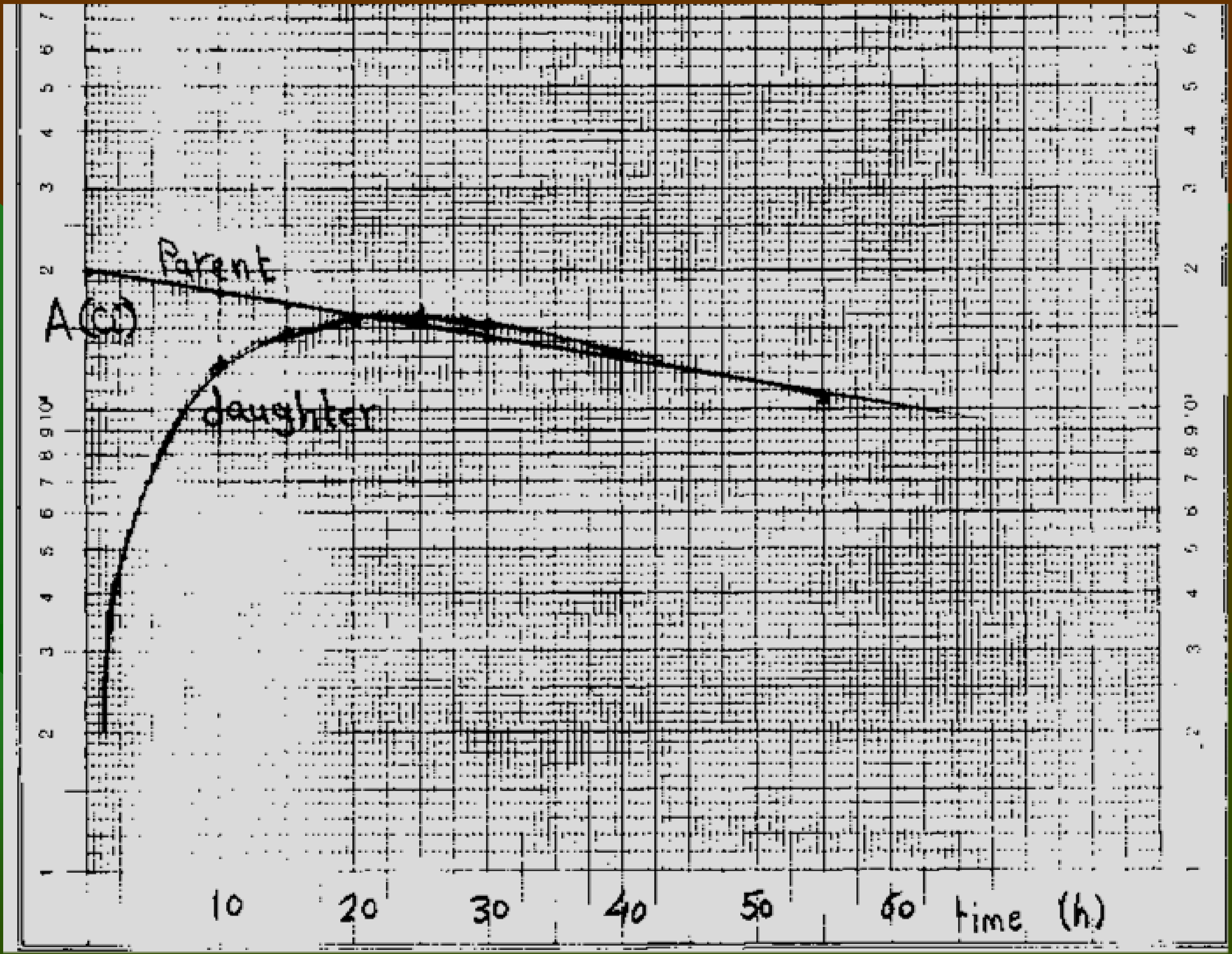
$$^{212}_{82}Pb \xrightarrow{T=10.6h} {}^{212}_{83}Bi \xrightarrow{66.3\%\,60.5m} {}^{212}_{84}Po$$

$$other\ ------{}^{212}_{83}Bi \xrightarrow{33.7\%\,60.5m} {}^{208}_{81}Tl$$



T(h)	0	10	15	20	25	30	40	60
A_{Mo}	2	1.8	1.711	1.625	1.54	1.464	1.32	1.07
A_{Tc}	0	1.278	1.497	1.576	1.571	1.548	1.3	1.07

Mo-99 (T=66.7h) decays to its daughter Tc-99m(6.03h)



Parent
A(Ci)
daughter
10
20
30
40
50
60
time (h)

To determine the time at which the concentration of the daughter is maximum .

Parent half lives

$$\frac{d(\lambda_B N_B)}{dt} = \frac{\lambda_B \lambda_A N_{Ao}}{\lambda_B - \lambda_A} \left(-\lambda_A e^{-\lambda_A t} + \lambda_B e^{-\lambda_B t}\right) = 0$$

$$\lambda_A e^{-\lambda_A t_{md}} = \lambda_B e^{-\lambda_B t_{md}}$$

$$\frac{\lambda_B}{\lambda_A} = \frac{e^{-\lambda_A t_{md}}}{e^{-\lambda_B t_{md}}} = e^{(\lambda_B - \lambda_A) t_{md}}$$

$$\ln\left(\frac{\lambda_B}{\lambda_A}\right) = (\lambda_B - \lambda_A)\, t_{md}$$

$$t_{md} = \frac{\ell n\left(\lambda_B / \lambda_A\right)}{(\lambda_B - \lambda_A)}$$

as $T_A = 10.6\ h \Rightarrow \lambda_A = \dfrac{0.693}{10.6} = 0.065\ h^{-1}$

$T_B = 60.5\ m \Rightarrow \lambda_B = \dfrac{0.693}{1.01} = 0.686\ h^{-1}$

$t_{md} = 3.78\ h$

The total activity at any time is given by

$$A(t) = \lambda_A N_A + \lambda_B N_B \tag{2.15}$$

$$A(t) = \lambda_A N_{A0} e^{-\lambda_A t} + \frac{\lambda_B \lambda_A N_{A0}}{\lambda_B - \lambda_A} \left(e^{-\lambda_A t} - e^{-\lambda_B t} \right)$$

$$\frac{dA(t)}{dt} = -\lambda_A^2 N_{A0} e^{-\lambda_A t} + \frac{\lambda_B \lambda_A N_{A0}}{\lambda_B - \lambda_A} \left(-\lambda_A e^{-\lambda_A t} + \lambda_B e^{-\lambda_B t} \right)$$

at $t = t_{max}$ $\qquad \frac{dA(t)}{dt} = 0$

$\therefore$ the total activity is maximum at time

$$-\lambda_A^2 N_{Ao} e^{-\lambda_A t}\left(1+\frac{\lambda_B}{\lambda_B-\lambda_A}\right)+\frac{\lambda_A\lambda_B^2}{\lambda_B-\lambda_A} N_{oA} e^{-\lambda_B t}=0$$

$$\lambda_A^2 N_{Ao} e^{-\lambda_A t}\left(1+\frac{\lambda_B}{\lambda_B-\lambda_A}\right)=\frac{\lambda_A\lambda_B^2}{\lambda_B-\lambda_A} N_{oA} e^{-\lambda_B t}$$

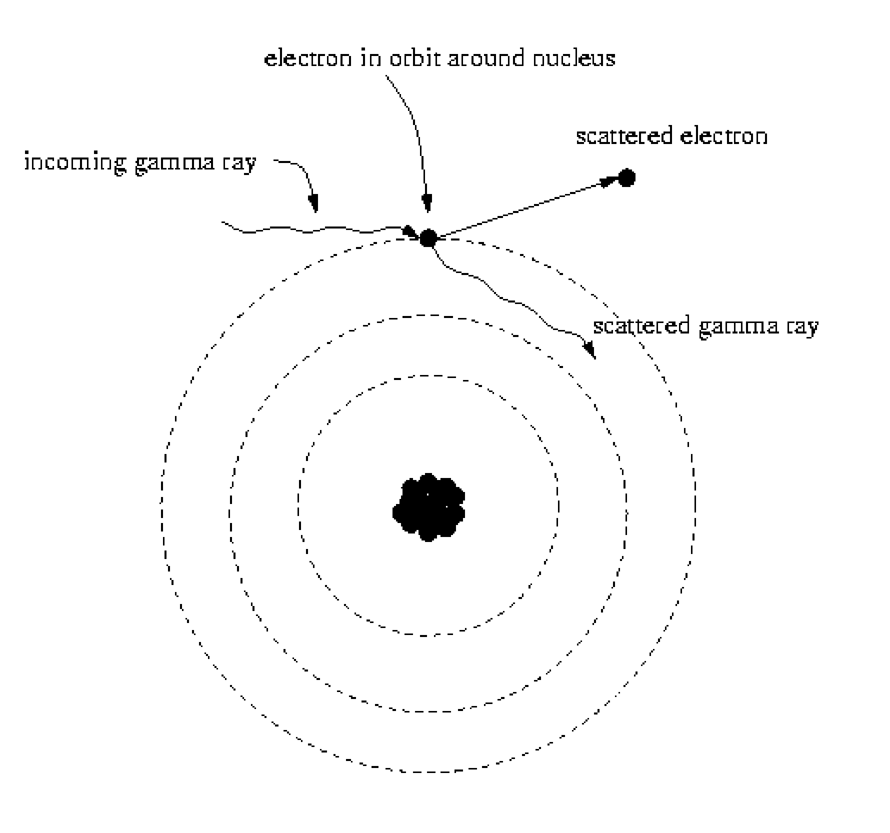
$$\lambda_A e^{-\lambda_A t}\ \frac{\lambda_B-\lambda_A+\lambda_B}{\lambda_B-\lambda_A}=\frac{\lambda_B^2}{\lambda_B-\lambda_A}\ e^{-\lambda_B t}$$

t_{mt}, the time when the total activity is maximum.

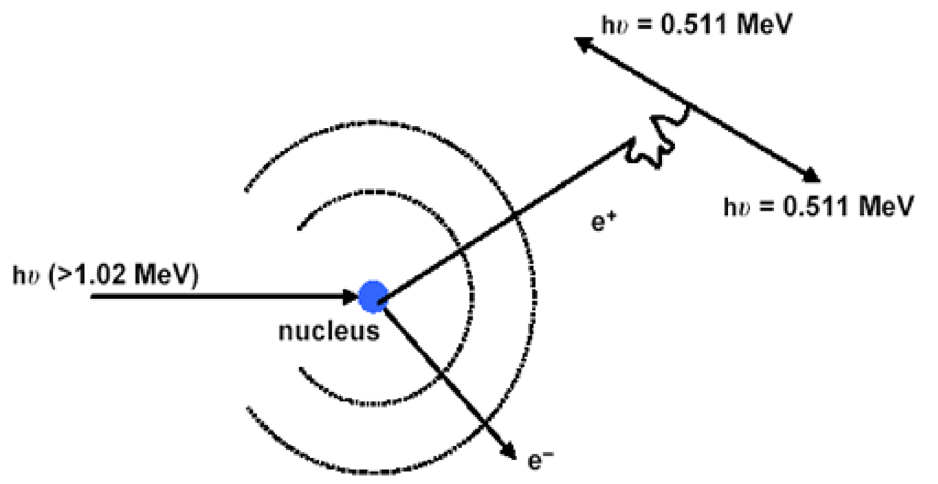
$$t_{mt}=\frac{1}{\lambda_B-\lambda_A}\,\ell n\left(\frac{\lambda_B^2}{2\lambda_A\lambda_B-\lambda_A^2}\right)$$

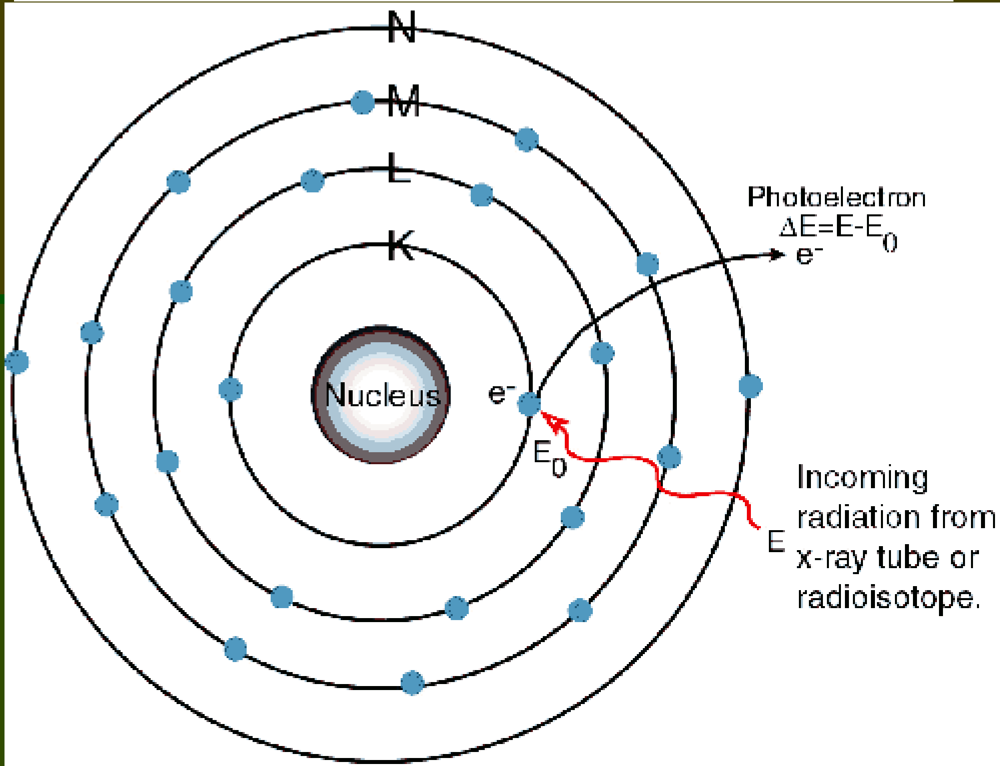
In the case when $T_A < T_B$ or $\lambda_A > \lambda_B$, no equilibrium is possible.

Attenuation Mechanism

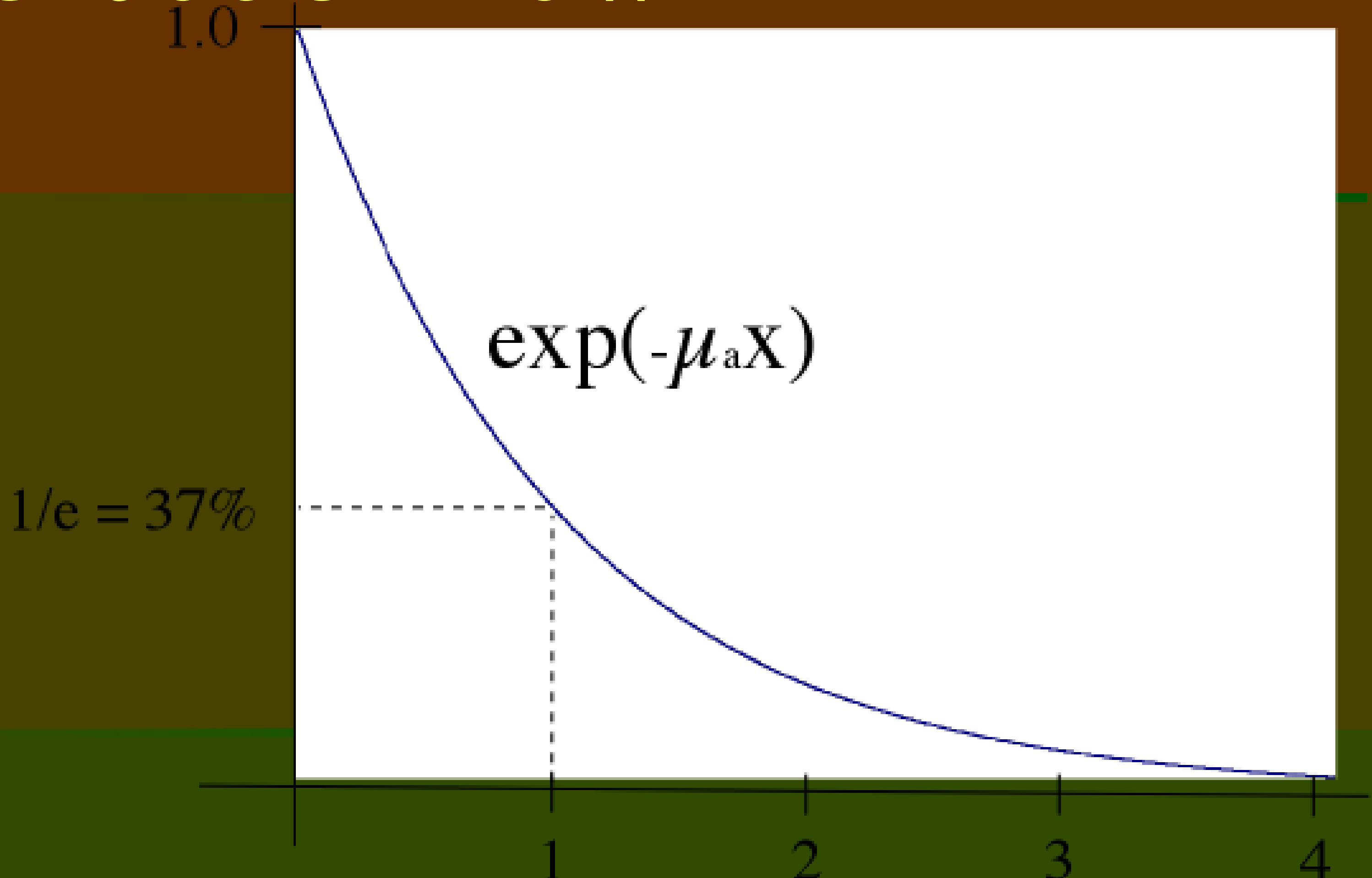


Compton Scattering:





Attenuation Law $I/I_o = e^{-\mu X}$

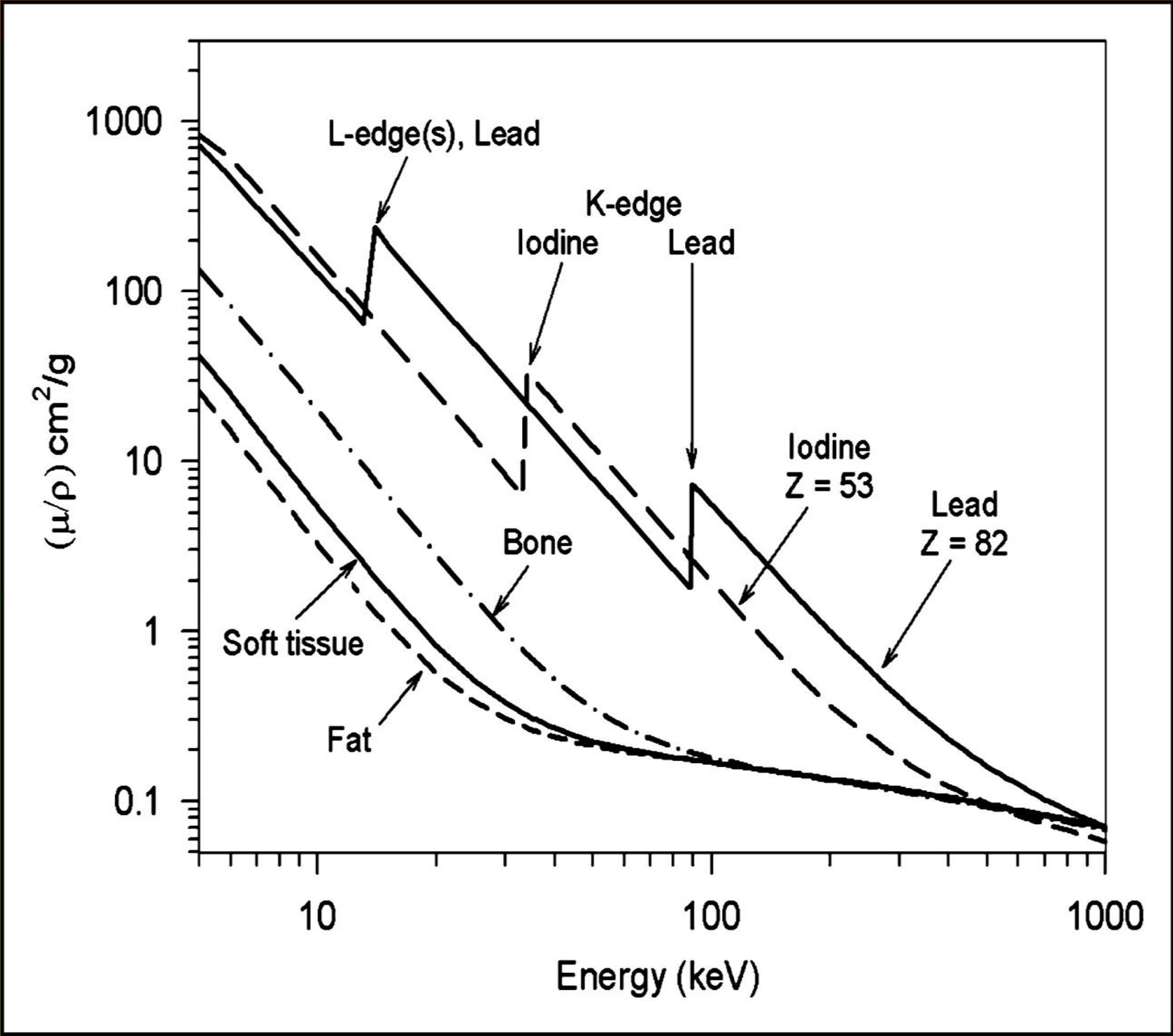


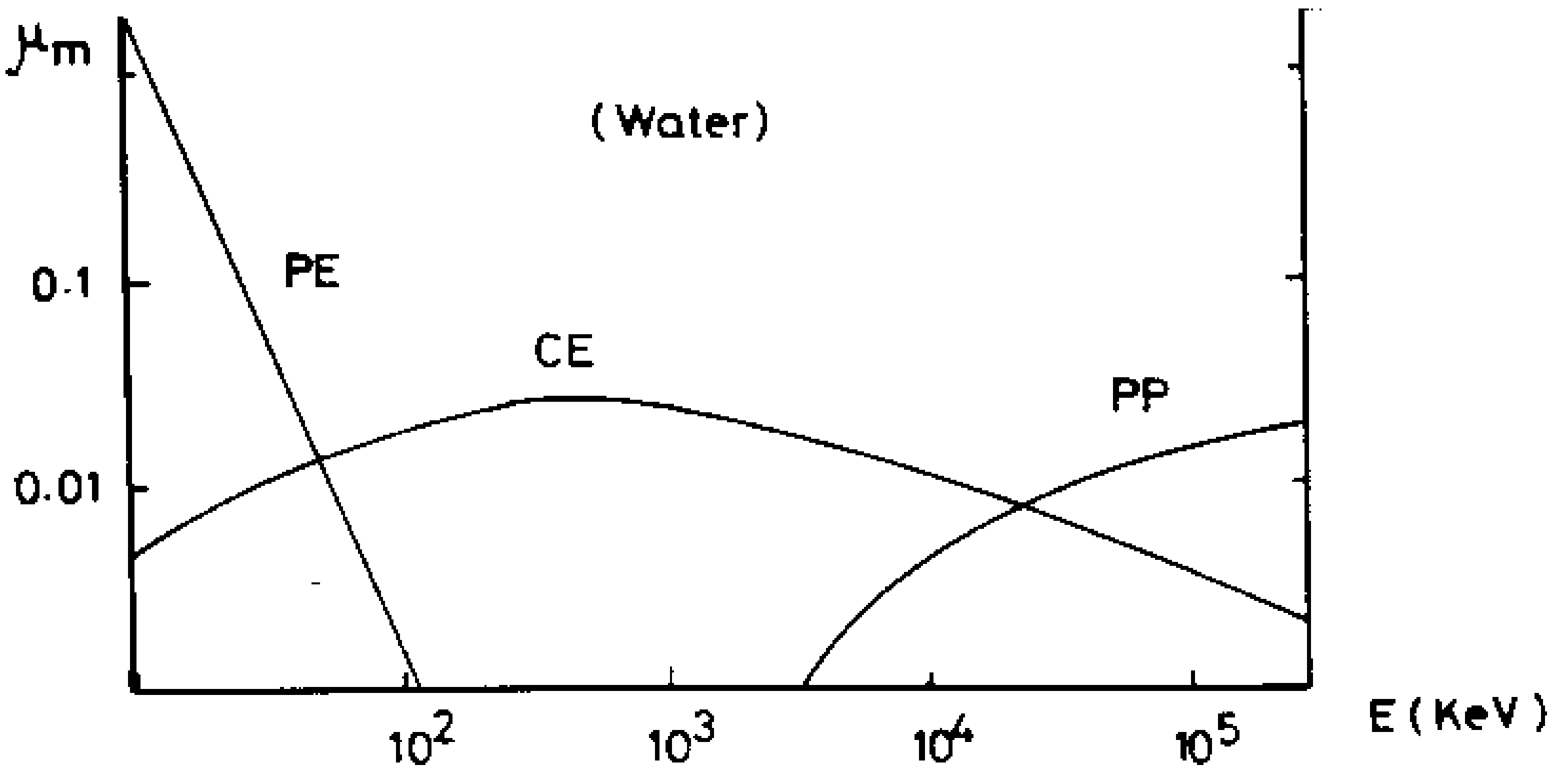
at $I = I_o/2$ $X = X_{½}$

One will find that $X_{½} = 0.693/\mu$

Mass attenuation coefficient for various tissues , lead , iodine

sharp rises are called K or L– edges.





μ_m
(Water)
0.1
0.01
PE
CE
PP
10^2
10^3
10^4
10^5
E (KeV)

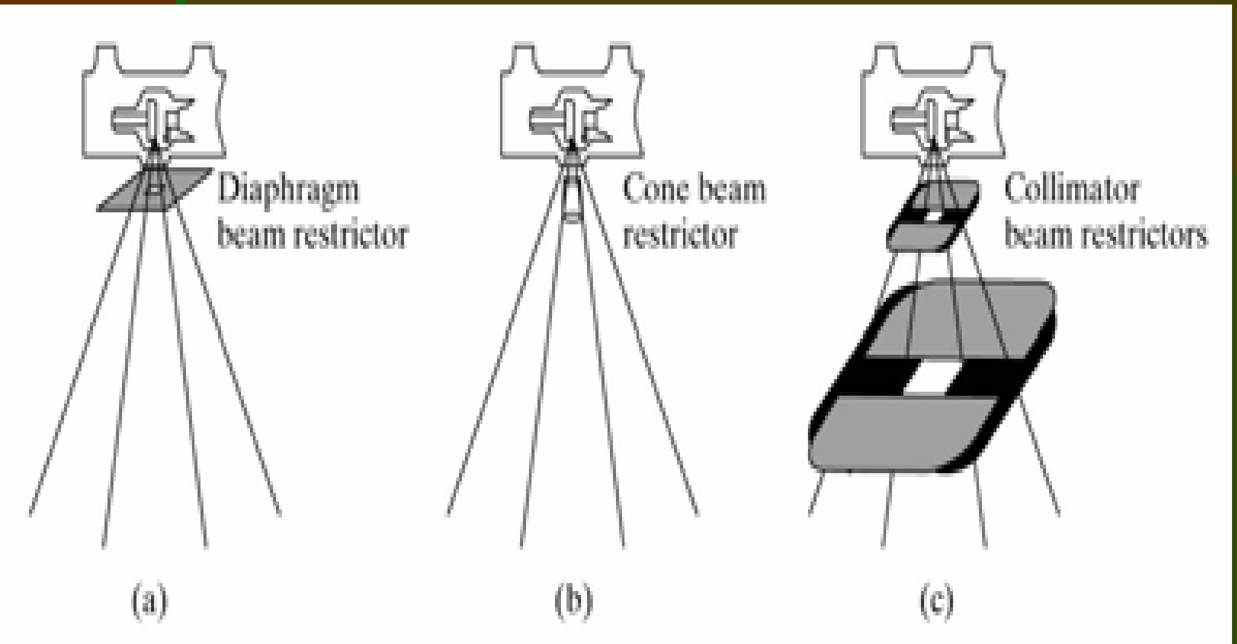
γ OR X – RAY IMAGING

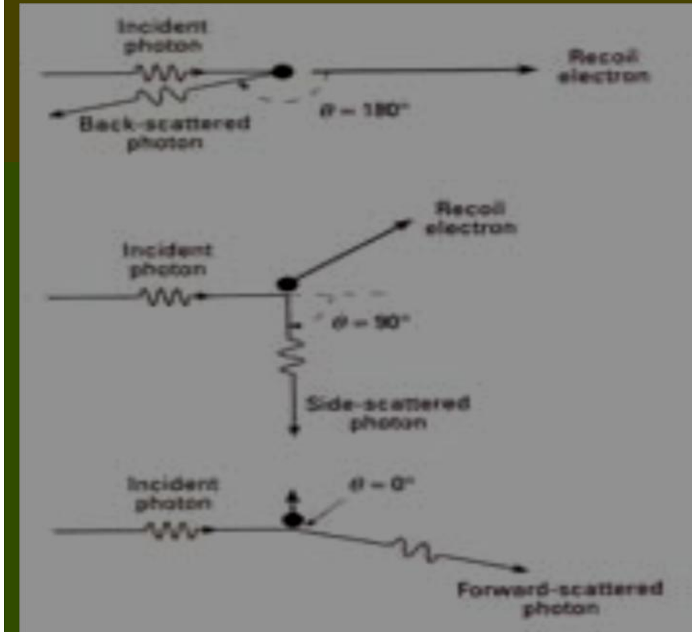
Body tissues attenuate photons in different amounts depending on their linear attenuation coefficients and photons energies.

This differential attenuation gives rise to contrast, and therefore the ability to differentiate tissues.

Since γ or X – ray is invisible; this image is converted to visible one by fluorescent screen, image intensifier, or film. The beam that emerges from the patient contains primary and scattered radiation. Since the primary beam contains useful information about the object being examined ,it is desirable to reduce the amount radiation to the film by means of grid.

This grid allows only that radiation which comes from the direction of the source to reach the imaging system. The scatter component may be also reduced by limiting the size of the X – ray field to the region to be examined.





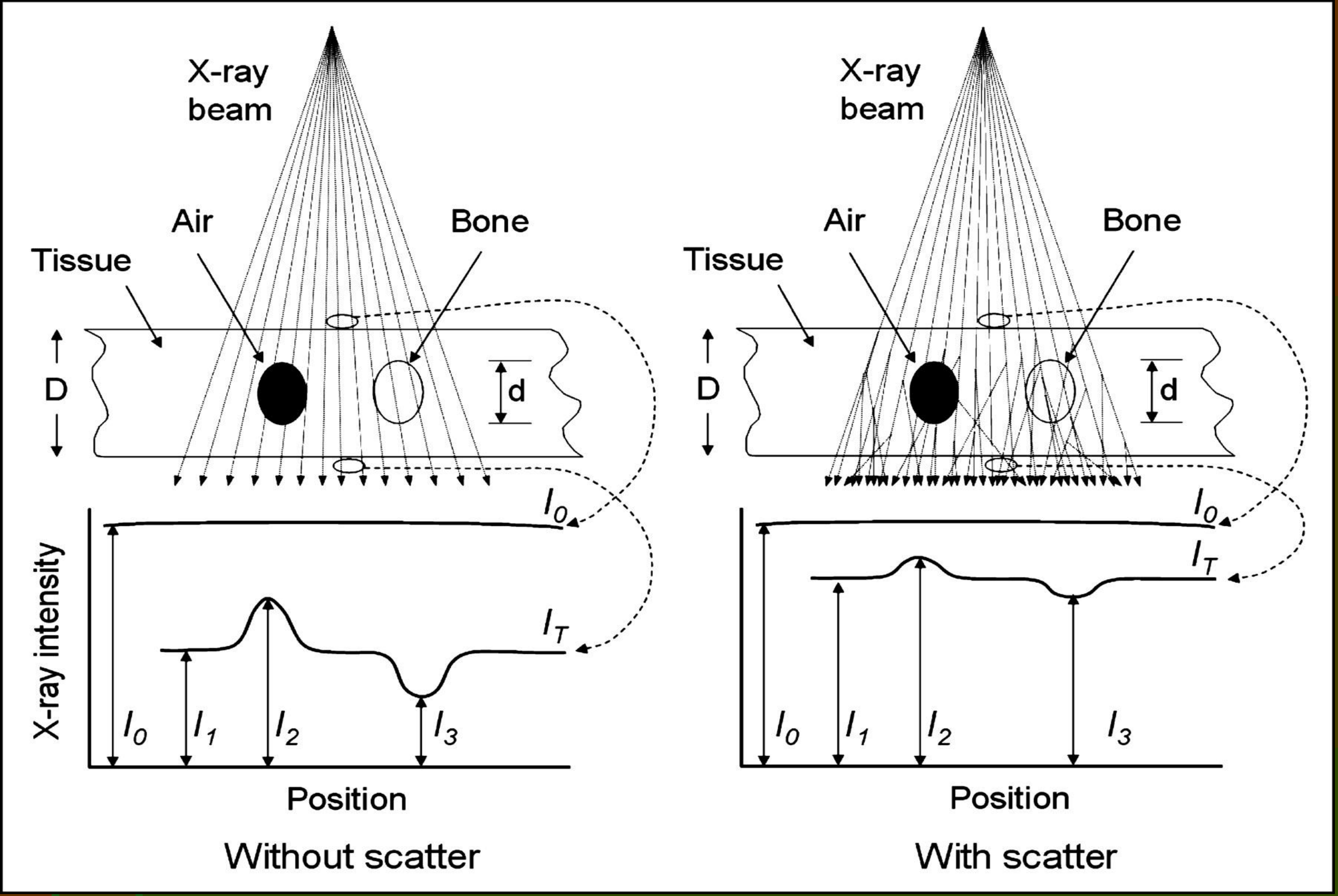
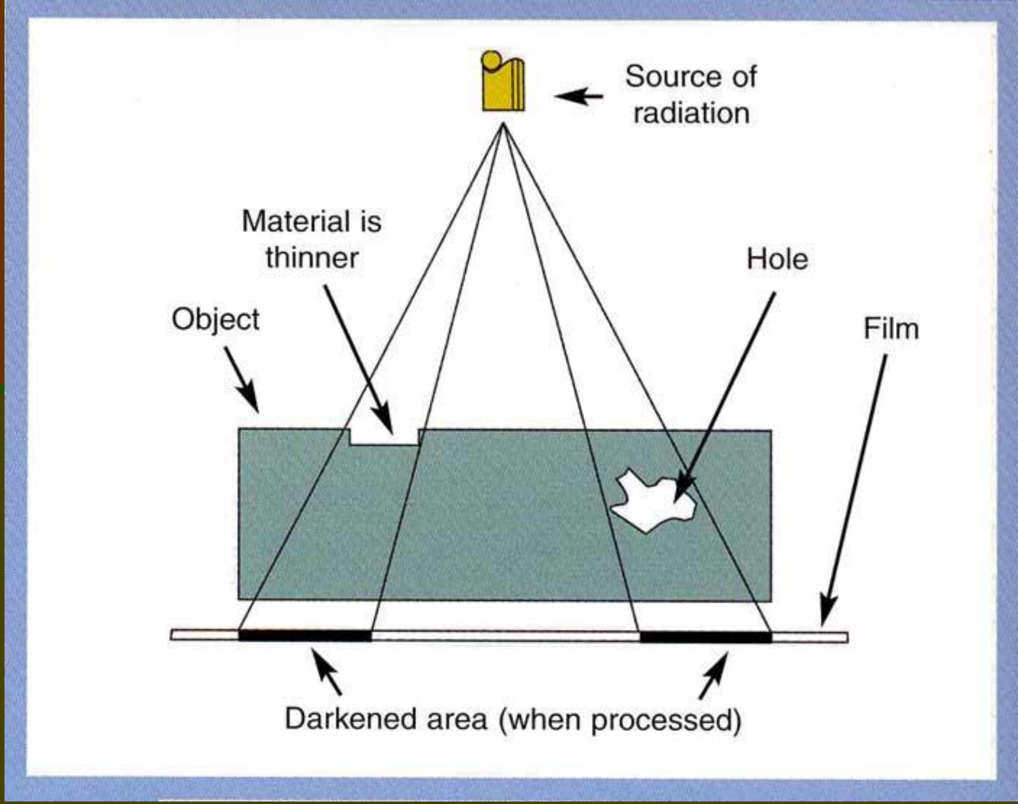


Image production with X – rays .



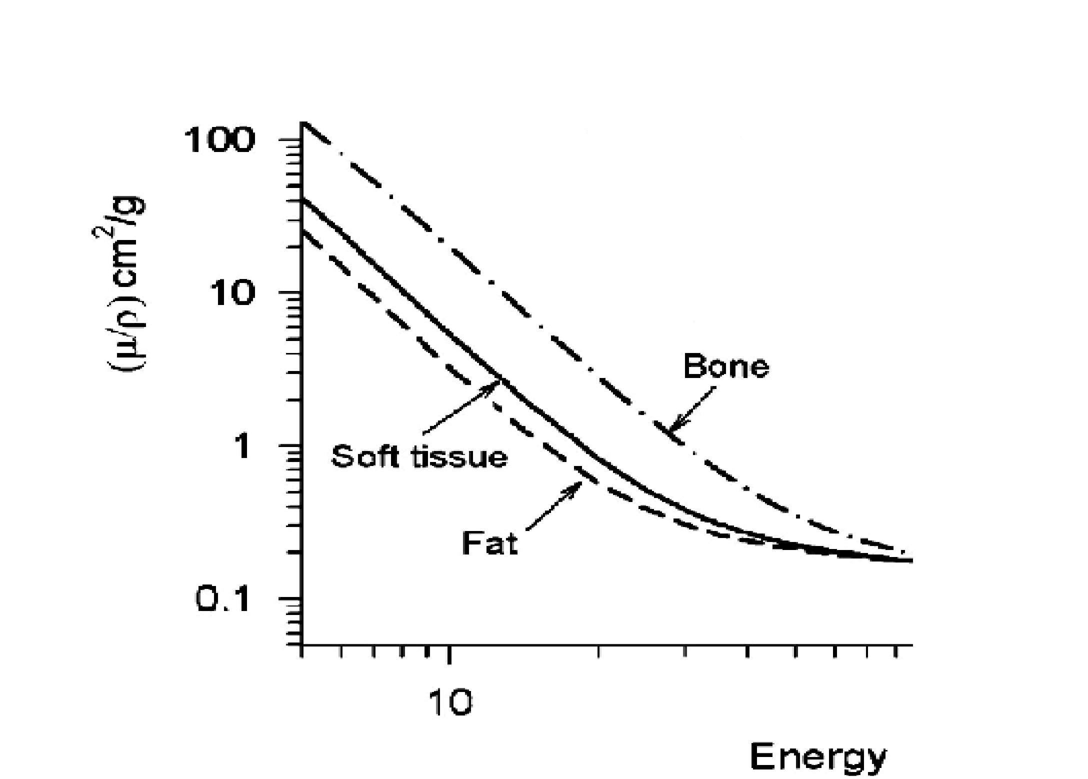
Imaging using γ source

Images Produced by Tissues

Fat, muscles and bone can be distinguished from one another in an X – rays in different ways.

Contrast in x-ray imaging.
Large contrast between bone and muscle Decreases with increasing energy (photoelectric absorption in bone is much larger at low energy)

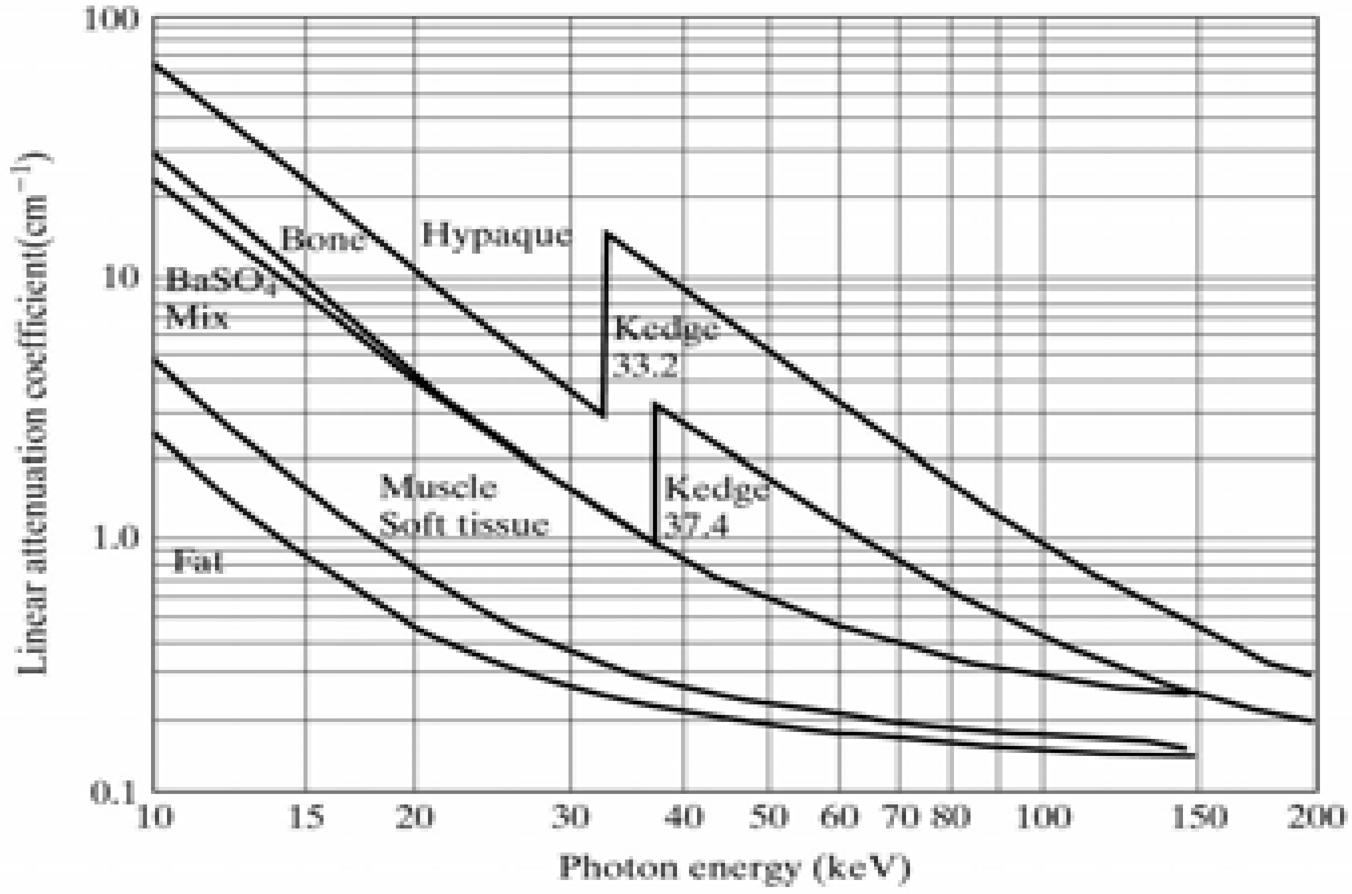
- Little contrast between muscle and other soft tissue
- Large difference between air and tissue (owing to difference in density)



Contrast agents

The two most common contrast agents are iodine (Z=53) and barium (Z=56).

These agents have relatively high atomic numbers, and they have K-shell electrons whose binding energies fall within the diagnostic x-ray energy range (30 - 40 keV)

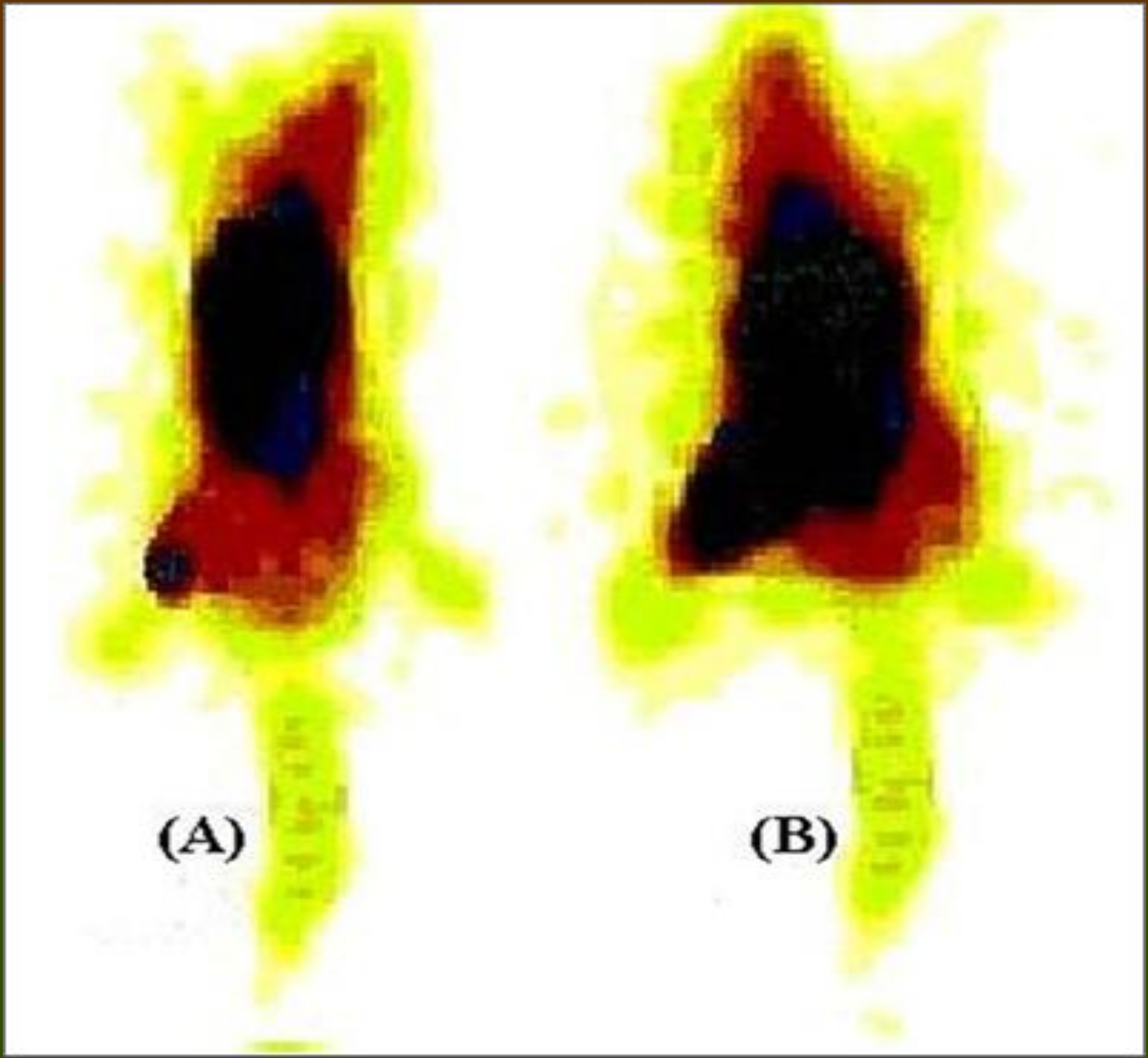


Iodine will cast a very dense shadow especially for energies just above its K – edge at 33.2 Kev, while barium shows the same effect just above 37.4 Kev.We

Images Produced by Contrast Media

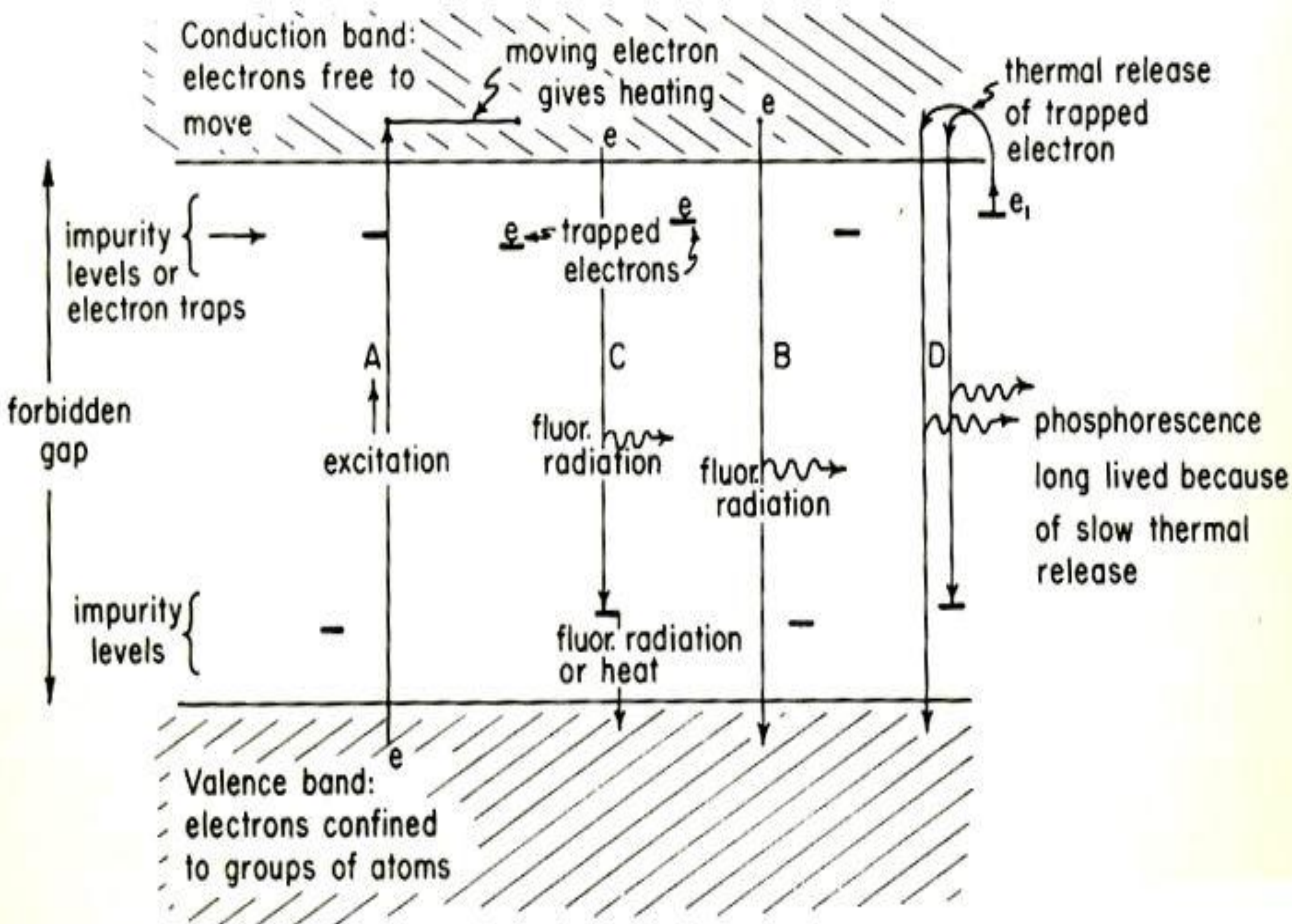
To visualize many organs in the body it is necessary to introduce into the patient a medium that is deposited in the organ and that absorbs X – rays either more or less than surrounding tissues.

Barium and Iodine absorb X- rays very strongly , and so organs filled with these agents transmit very little radiation . The absorption data for barium and iodine are plotted in figure for suspensions of these materials as they are commonly used. Both show a sharp discontinuity in the adsorption curve at the K – edge.


(A)
(B)

PHOSPHORS
(FLUORESCENT MATERIALS)

The conversion of X – ray energy to light makes use of the fluorescence and phosphorescence of certain crystals by the mechanism illustrated in figure .


Conduction band:
electrons free to
move
moving electron
gives heating
e
e
thermal release
of trapped
electron
e_1
impurity
levels or
electron traps
e
trapped
electrons
e
A
C
B
D
forbidden
gap
excitation
fluor.
radiation
fluor.
radiation
phosphorescence
long lived because
of slow thermal
release
impurity
levels
fluor. radiation
or heat
e
Valence band:
electrons confined
to groups of atoms

the possible energy levels for the electrons are a continuous band or what is called valence band . If these electrons are excited by X–rays, they can move up to the conduction band where the electrons will be free.

Electrons cannot exist in the forbidden gap. However, if a pure crystal contains small amount of impurity discrete positions for electrons are produced in the forbidden gap. Impurity levels may trap electrons or release them to the conduction band by thermal agitation

RADIOGRAPHIC IMAGES

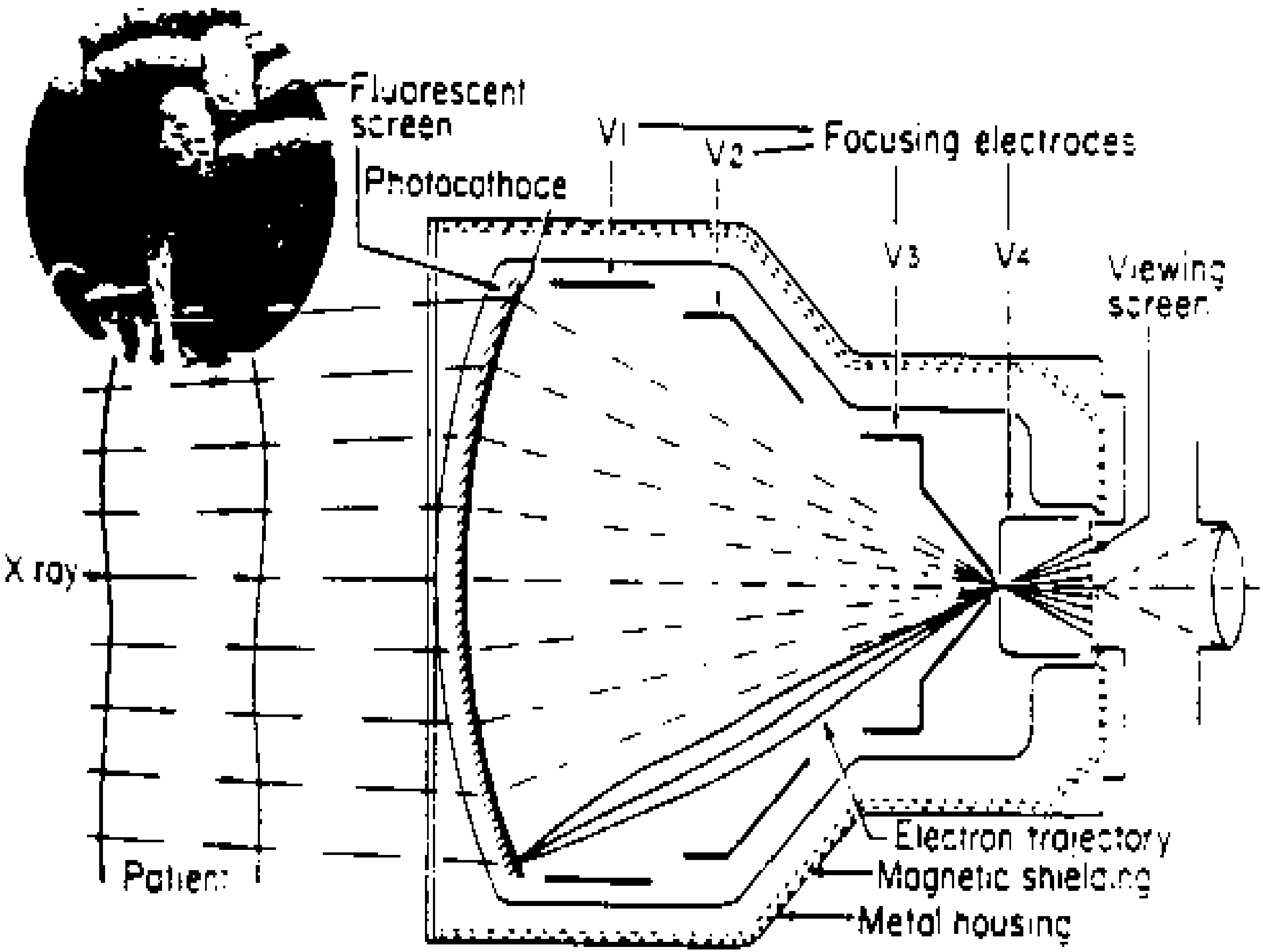
The primary radiological image described in the last section includes the information concerning the patient the radiologist would like to obtain.

However , this information is not in a useful form , and it is necessary to convert it by some type of imaging device to make it visible to radiologist this can be done by producing a visible image on the fluorescent screen of an image intensifier.

Tube Image Intensifier

An intensifier is illustrated schematically in figure. X – rays from the source passes through the patient and enters the evacuated intensifier tube through the glass or metal envelope and aluminum screen on which is deposited fluorescent material.

This material absorbs some 60% to 70% of the X – rays, converting their energy into fluorescent light. This light is absorbed by photocathode, which ejects low energy photoelectron into the evacuated tube. In a typical absorption of one X – ray photon about 100 photoelectrons are emitted.



Fluorescent screen
Photocathoce
V1
V2
Focusing electroces
V3
V4
Viewing screen
X ray
Patient
Electron trajectory
Magnetic shielcing
Metal housing

These photoelectrons are accelerated and focused by the high voltage between the two ends of the tube to form a very bright image on the output phosphor or viewing screen. This image may be some 10,000 times brighter than the image on the input fluorescent screen for two reasons.

1- In the first place , the image may be reduced in diameter from about 25 cm to 2.5 cm , i.e. by a factor of 10 in diameter or of 100 in area .

Since the same number of electrons reach the output phosphor as leave the input phosphor, the number of electrons per unit area striking the output phosphor will be increased by 100 times .

2- In addition these electrons are accelerated to a high energy within the tube and on striking the output phosphor will each produce 100 times as many light photons, hence the total brightness gain is about 100 x 100 = 10,000.

The viewing screen may be observed by an optical system that enlarges it for viewing to about the same size as the original. In this process no loss in brightness; the optical system will transmit all light.

There some demands to yield the maximum signal for a given exposure :

1 – The fluorescent screen should be thick enough to absorb most of the X – ray and yet thin enough to insure that the light from the screen does not spread much before reaching the photocathode. This could be achieved by growing needlelike crystals CsI on aluminum substrate.

With this structure CsI can be made thick enough to absorb most of the radiation and yet the light generated is carried to the photocathode without spreading by the needlelike crystals, which acts as light pipes. With such a design one achieves both excellent absorption of X – rays and good resolution.

2 – The photocathode should be chosen to efficiently convert the light from the screen into photoelectron.

A structure in a patient is visible by: The *resolution* and *sharpness* of the image. The *contrast* between it and adjacent tissues caused by differences in the transmission of photons.

64 x 64

256 x 256

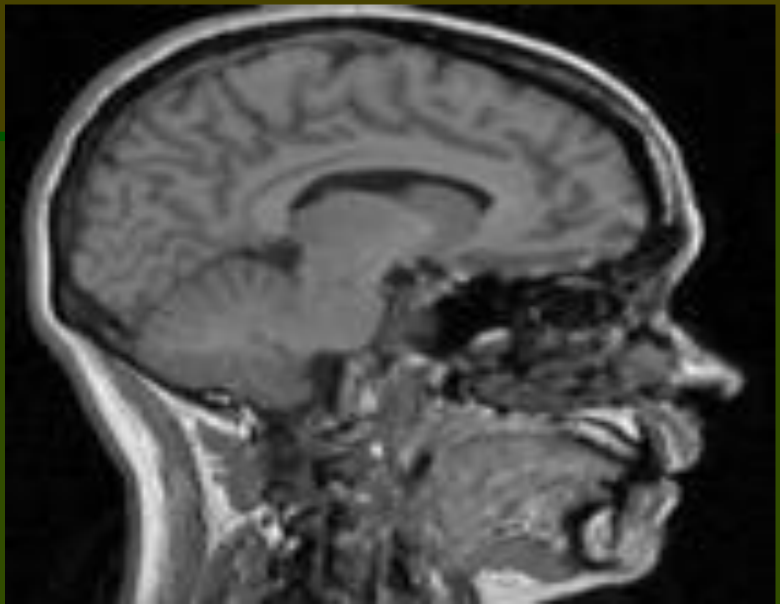
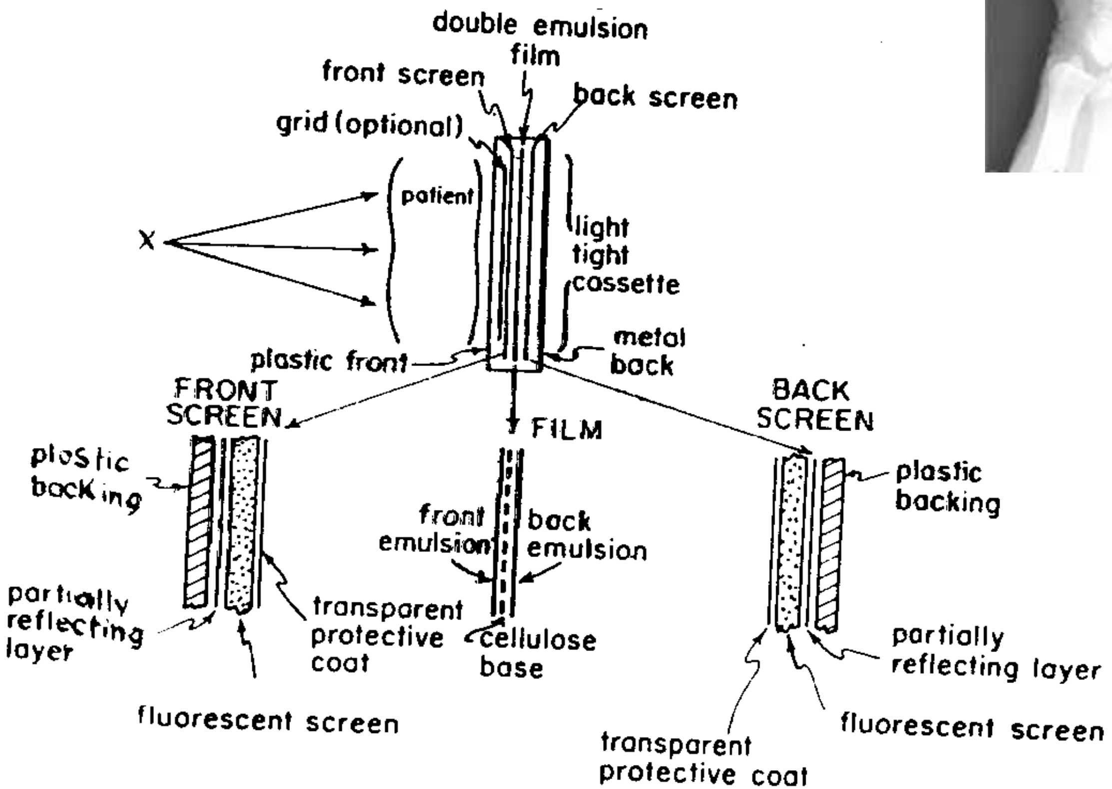


Image Produced on Full Size Film

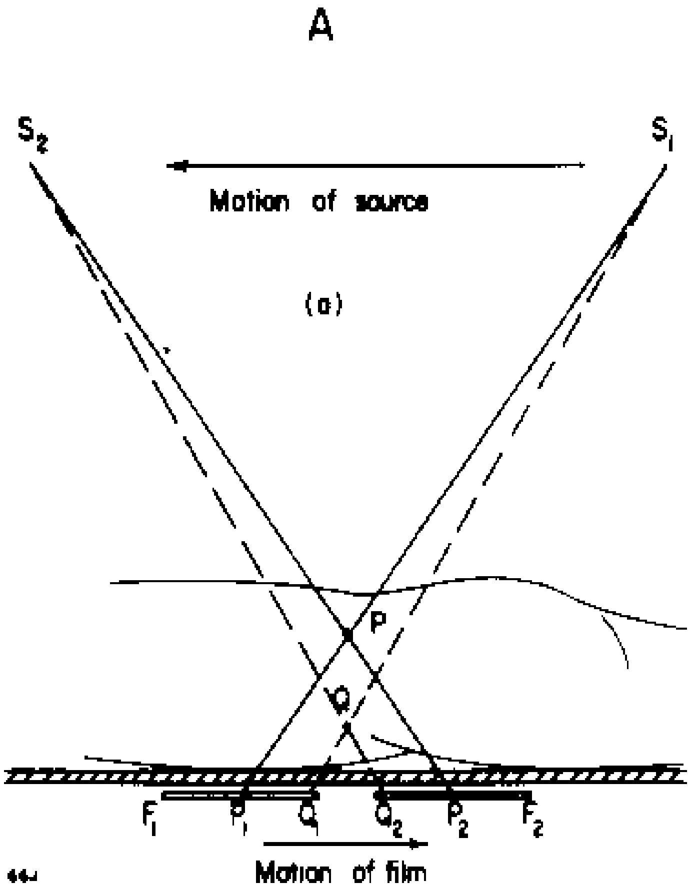


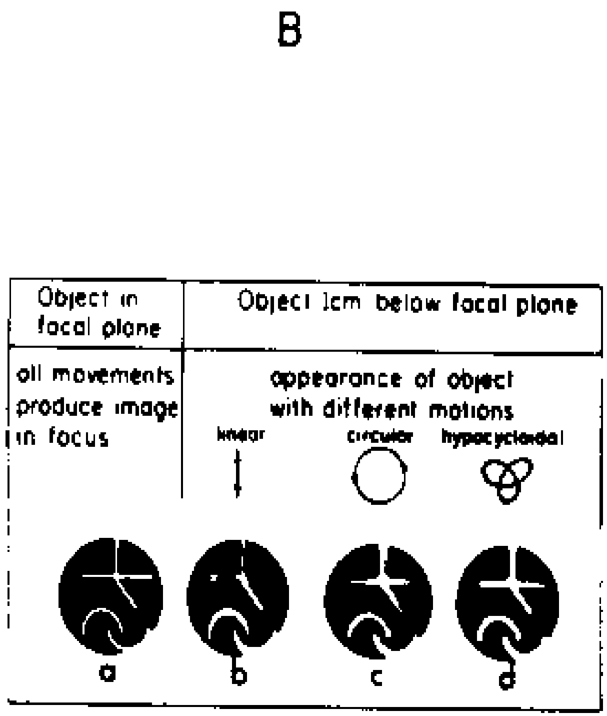
To increase the sensitivity the film is sandwiched between two fluorescent screens

This screen absorbs X-rays and emits visible and ultraviolet light, which exposes the film. The film consists of a plastic base coated on both front and back with relatively thick emulsion.

The front emulsion is exposed mainly by light from the front screen, and the back screen. Crossover: some light from the front screen reaches the back emulsion and some light from the back screen reaches the front emulsion.

TOMOGRAPHAY





Tomographic blurring movements

The X – ray source is moved in one direction from S_1 to S_2 while the film is moved in the opposite direction from P_1 to P_2 at a speed such that a line joining the center of the film to the source passes through P the center of the region of interest within the patient .

From the diagram, it is clear that the image of P will clear at P1 the center of the film for all positions of the film . On the other hand, structures in the other plane as Q will produce a blurred image extending from Q1 near one end of the film to Q2 at the other end .

The greater the distance, or the angle of movement of the X – ray tube, the narrower the slice that is in focus the greater is the blurring of overlying structures.